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Abstract

This is the Space Station Freedom (SSF) Evolution Study 1993 Final Report, performed under NASA Contract NAS8-38783, Task Order 5.1. This task examined: (1) the feasibility of launching current National Space Transportation System (NSTS) compatible logistics elements on expendable launch vehicles (ELVs) and the associated modifications and (2) new, non-NSTS logistics elements for launch on ELVs to augment current SSF logistics capability.

Key Words

Space Station Freedom
Space Station Evolution Technology
Logistics
Expendable Launch Vehicles
Unpressurized Logistics Elements
Pressurized Logistics Elements

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**Space Station Evolution Study
Final Report
September 1993**

**NASA Contract NAS8-38783
Task 5.1 Logistics System Elements
ELV-Delivered Logistics Carrier Evaluation**

**Spruce M. Cox
David B. Evans**

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Logistics Study/9-2-93/rrg

This document is the September, 1993, final report from the Space Station Evolution Study, contract NAS8-38783, Task 5.1, Logistics System Elements. This task was conducted by the Space Station Freedom (SSF) Applications Group, Boeing Defense and Space Group, Huntsville, Alabama, for NASA Marshall Space Flight Center. The purpose of the study was to perform conceptual evaluations of SSF logistics carriers launched on expendable launch vehicles.

The statement of work for this task originally contained four subtasks: (1) 5.1.1.1, ELV Delivered Logistics Carrier Evaluation; (2) 5.1.1.3, Non-STS/ELV Logistics Packaging; (3) 5.1.1.2, Shuttle/SSF Logistics Element Optimization; and (4) 5.1.2.1, Expendable Logistics Carrier Evaluation. In May, in support of SSF restructure activity within NASA, the COTR expanded the scope of the first two tasks and verbally directed us to expend remaining study resources on them. He directed us to stop the other two tasks.

This report details our efforts on tasks 5.1.1.1, ELV Delivered Logistics Carrier Evaluation, and 5.1.1.3, Non-STS/ELV Logistics Packaging.

Overview

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- Purpose
- Approach
- Groundrules
- Issues
- SSF Logistics Elements
- Launch Vehicle Characteristics
- Pressurized Logistics Carriers
 - STS-Compatible
 - ELV-Optimized
- Unpressurized Logistics Carriers
 - STS-Compatible
 - ELV-Optimized
- STS/ELV Mixed Fleet Logistics
- Scenario Evaluation--Mass Properties
- Alternate Carrier Return Concepts
- Summary

The purpose of this study was to perform conceptual evaluations of SSF logistics carriers launched on expendable launch vehicles. Two evaluations were performed: (1) modifications of current STS-compatible carriers for launch on an ELV and return on STS, and (2) new carriers intended for launch on an ELV and either non-STS reentry or reuse on-orbit. Study focus was on carrier concepts. Study products for individual logistics carriers and mods conceived were conceptual design sketches, mass properties estimates, and operational considerations.

ELV-Delivered Logistics Carriers Study

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- **Purpose**
 - Evaluate concepts for SSF Logistics Carriers launched on ELVs
- **Approach**
 - Identify minimum mods to existing STS-compatible carriers
 - ELV delivery
 - STS return
 - Define new ELV-optimized carriers
 - ELV delivery
 - Non-STS reentry or reuse on-orbit
 - Characterize carriers/mods
 - Structural concept
 - Mass properties estimates
 - Operational considerations
- **Groundrules**
 - Evaluate PLM, MPLM, PM, ULC, COC, CNC, DCC
 - Evaluate provisions for late access
 - Use worst case of Titan IV and Ariane V load factors

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ELV-Delivered Logistics Issues

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- Range safety requirement for payload destructive charge vs SSF safety requirement of no pyrotechnics
- Limited CTV power/cooling support to carriers (2215 W PLM requirement including CR for additional refrigerators/freezers)
- Late access
 - Into ELV shroud (unique shroud probably required)
 - Into vertical PLM/MPLM (hatch/rail mods, GSE required)
- ELV-delivered carrier stowage at SSF prior to STS return (location/duration)
- Returnable (STS compatible) carriers compromise ELV delivery efficiency due to strongback mass
- All cargo (including logistics payload items) must be qualified for ELV environments
- Use of Ariane V for PM involves airlifting carriers with hazardous cargo

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This section summarizes the SSF logistics carriers currently in development. They are all intended for launch and return in STS. The STS middeck also carries SSF logistics but was not evaluated in this study.

SSF Logistics Elements

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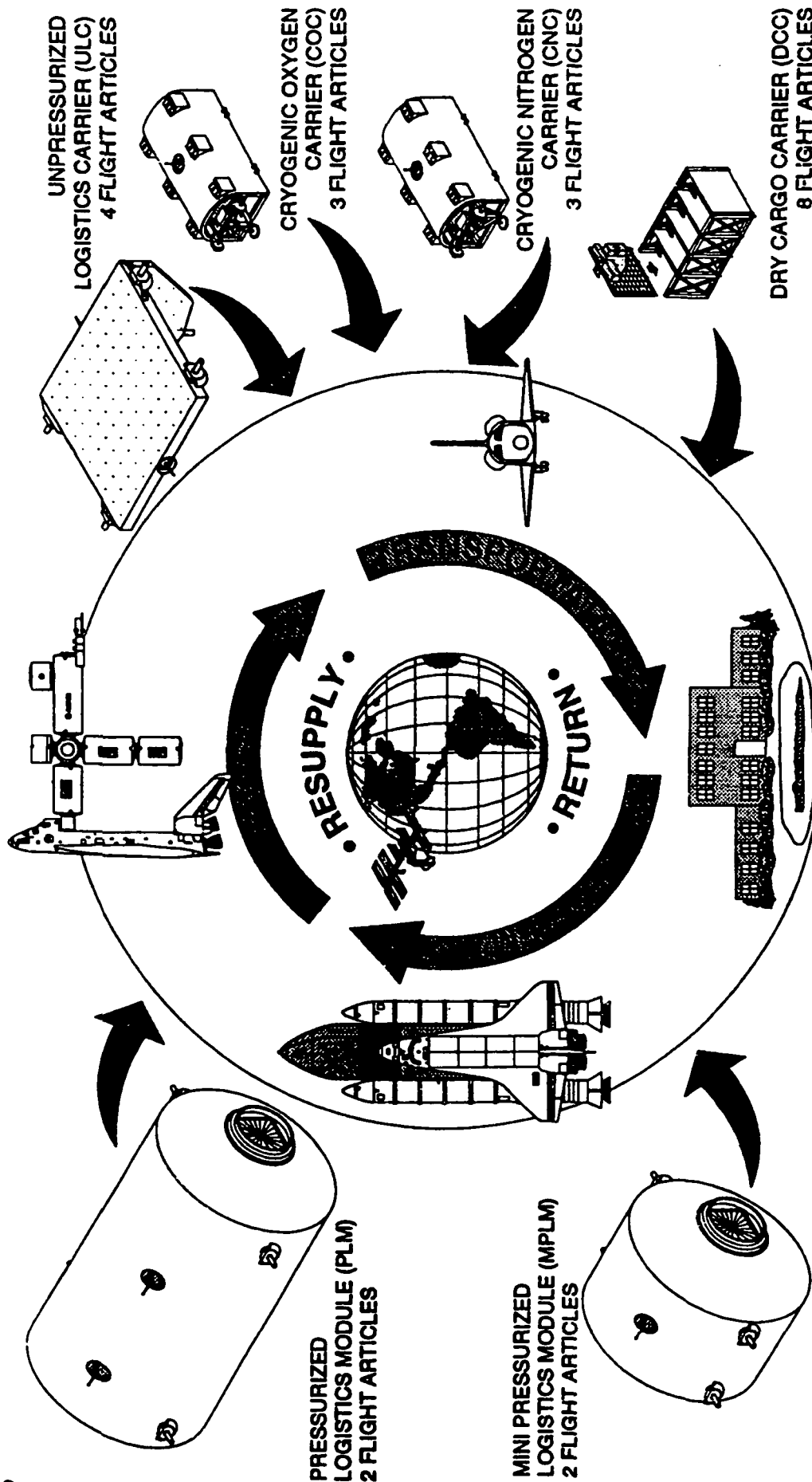
- Overview
- Pressurized Logistics Module (PLM)
- Mini Pressurized Logistics Module (MPLM)
- Propulsion Module (PM)
- Unpressurized Logistics Carrier (ULC)
- Cryogenic Oxygen Subcarrier (COC)
- Cryogenic Nitrogen Subcarrier (CNC)
- Dry Cargo Subcarrier (DCC)

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Logistics Element (LE Overview)

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LOGISTICS ELEMENTS ARE MAJOR COMPONENTS OF THE SYSTEM USED TO TRANSPORT CARGO TO AND FROM THE SPACE STATION

MSV 0200

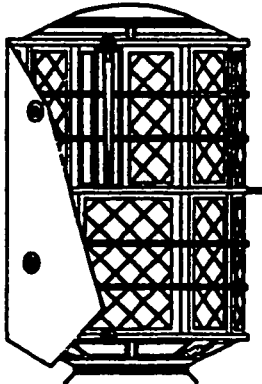
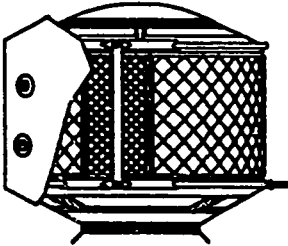
A new weight estimate from Alenia dated June 15 puts MPLM tare weight at 7688 lbs.

Configuration & Characteristics

Current PLM & MPLM

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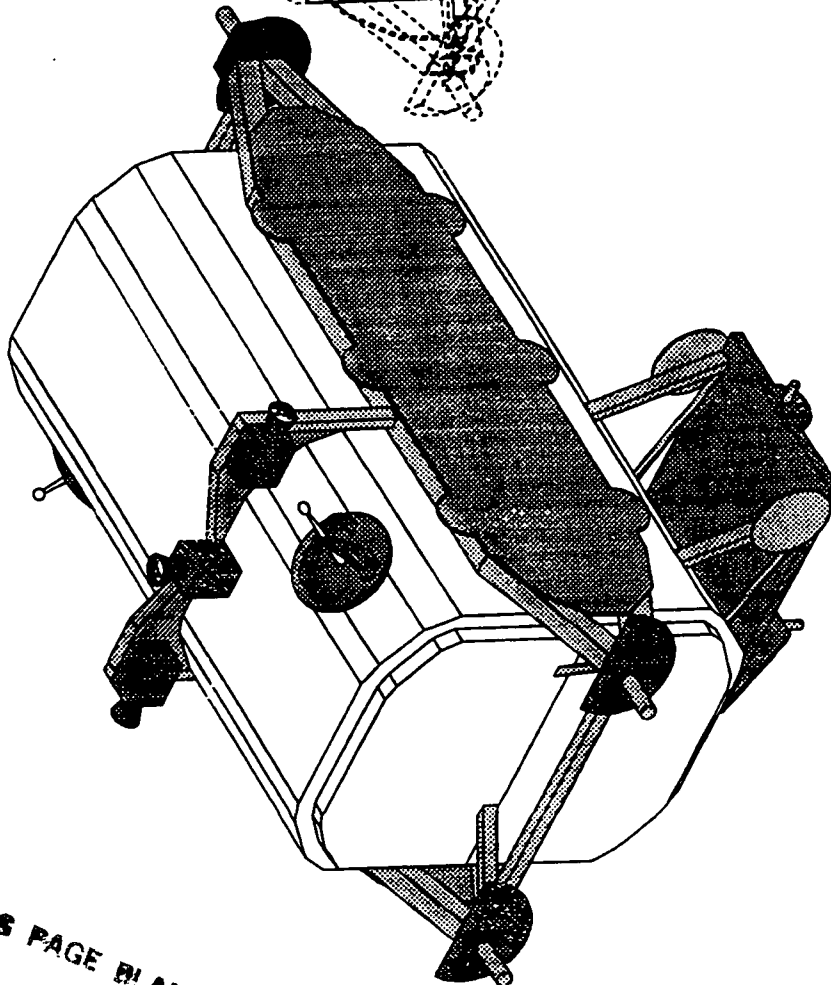
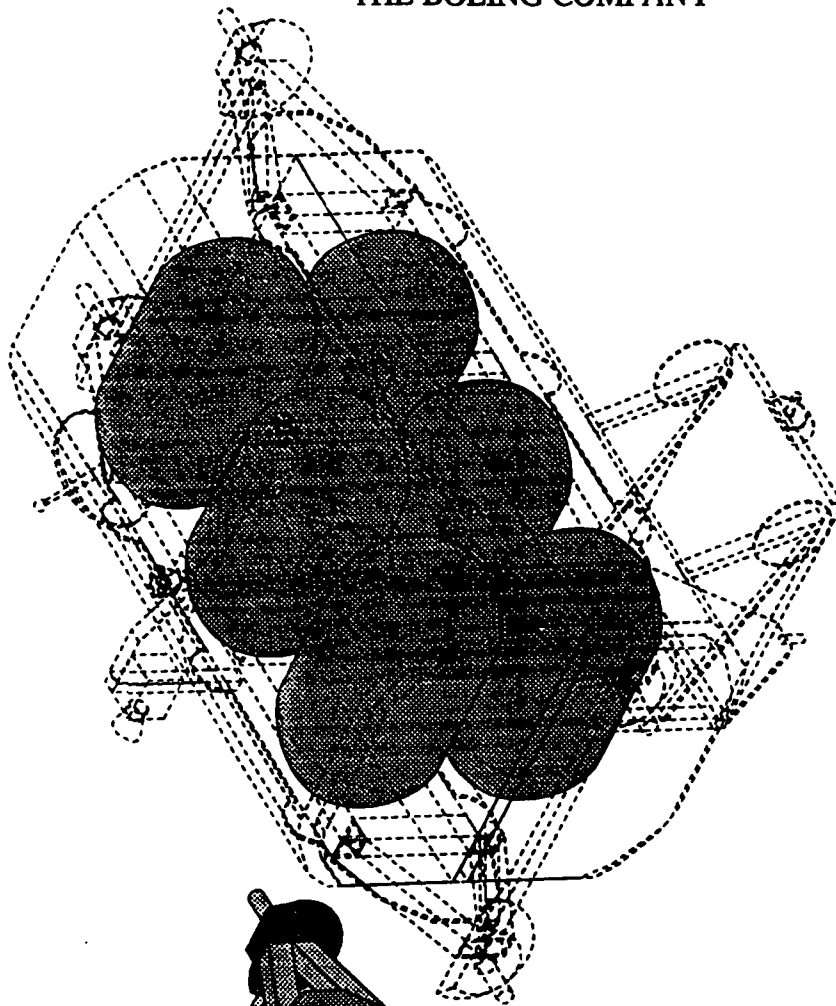
Current PLM	Current MPLM
 Tare Weight = 11,498 lbs • Subsystem Outfitting = 2,623 lbs • Distribute 3 KW Power • Reject 3 KW Heat • MM/Debris Shielding = 1,778 lbs • Structures/Mechanisms = 7,097 lbs Cargo Transportation Capability = 22,886 lbs • 12 Passive Stowage Racks = 10,932 lbs • 5 Passive User/Payload Racks = 6,060 lbs • 2 Refrigerator/Freezer Racks = 2,342 lbs • 4 Aisle Storage Containers = 3,552 lbs	 Tare Weight = 8,346 lbs • Subsystem Outfitting = 1,482 lbs • Distribute 3 KW Power • Reject 3 KW Heat • MM/Debris Shielding = 1,001 lbs • Structures/Mechanisms = 5,863 lbs Cargo Transportation Capability = 9,275 lbs • 3 Passive Stowage Racks = 2,733 lbs • 2 Passive User/Payload Racks = 2,424 lbs • 2 Active Racks (⊕ PMC) = 2,342 lbs • 2 Aisle Storage Containers = 1,776 lbs

BOTH THE MPLM AND PLM ARE DESIGNED TO ACCOMMODATE 1 EA ACTIVE REFRIGERATOR/FREEZER RACK AND FREEZER RACK

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Propulsion Module



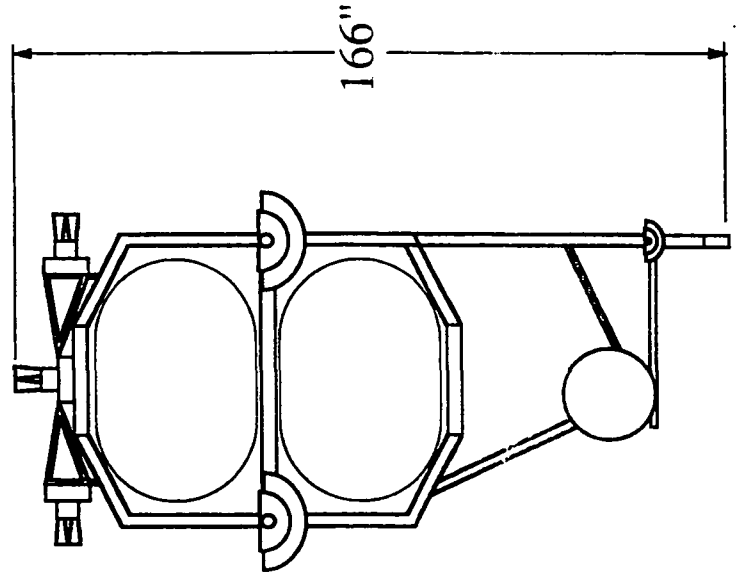
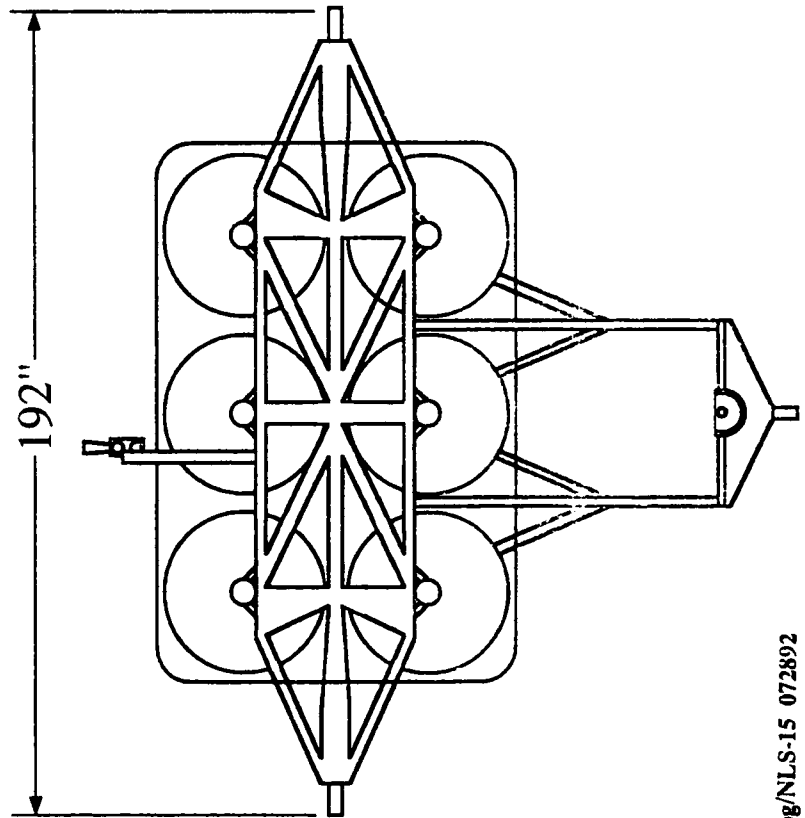
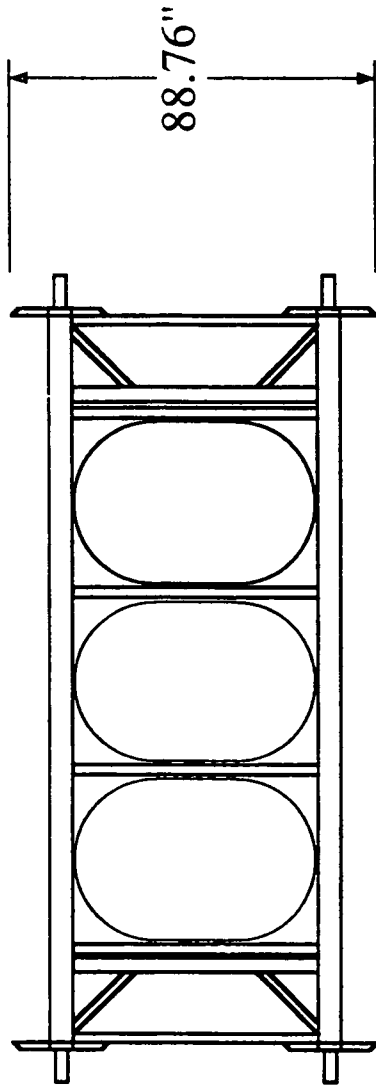
Propulsion Module
Dry WT = 4,632
Wet WT = 11,032

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Propulsion Module Layout

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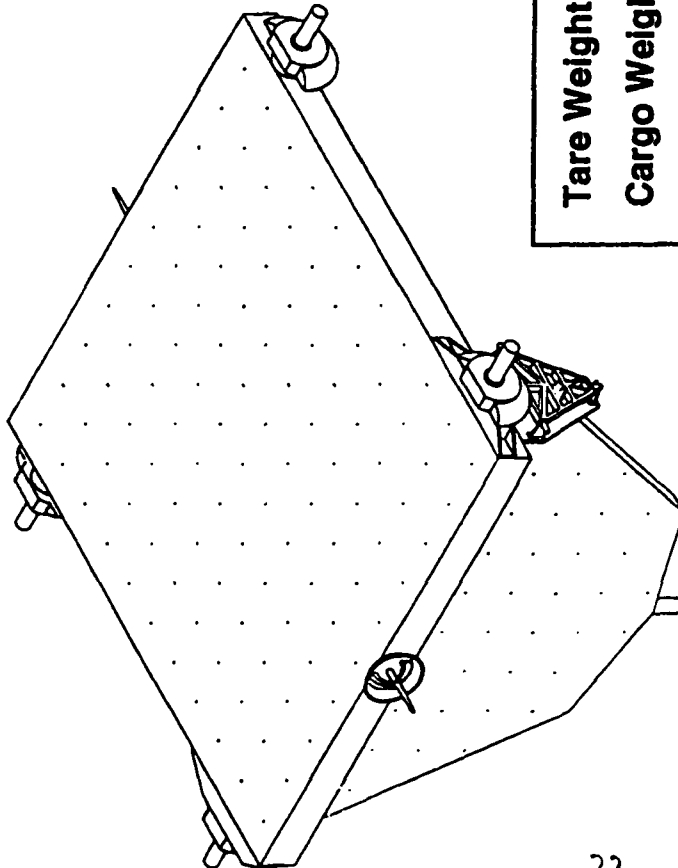
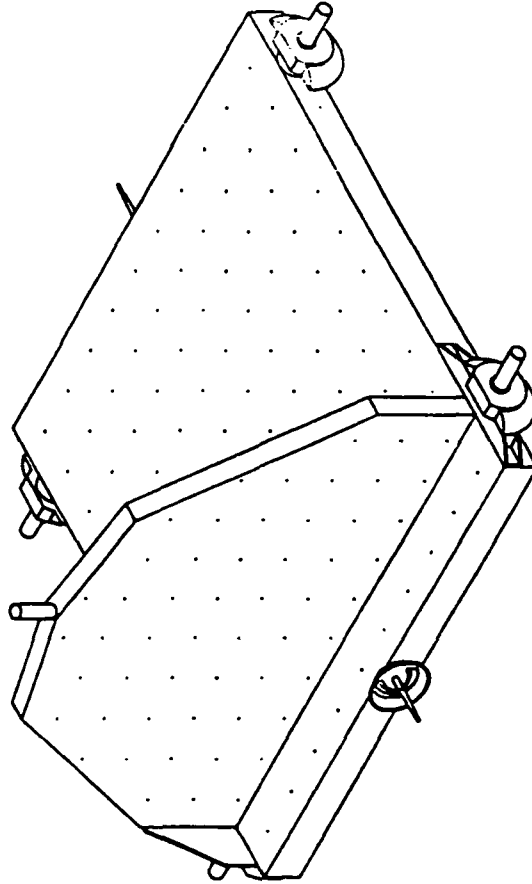


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Preliminary ULC Configuration

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Tare Weight = 3,445 Lbs
 Cargo Weight = 15,565 Lbs
 Total Weight = 19,010 Lbs

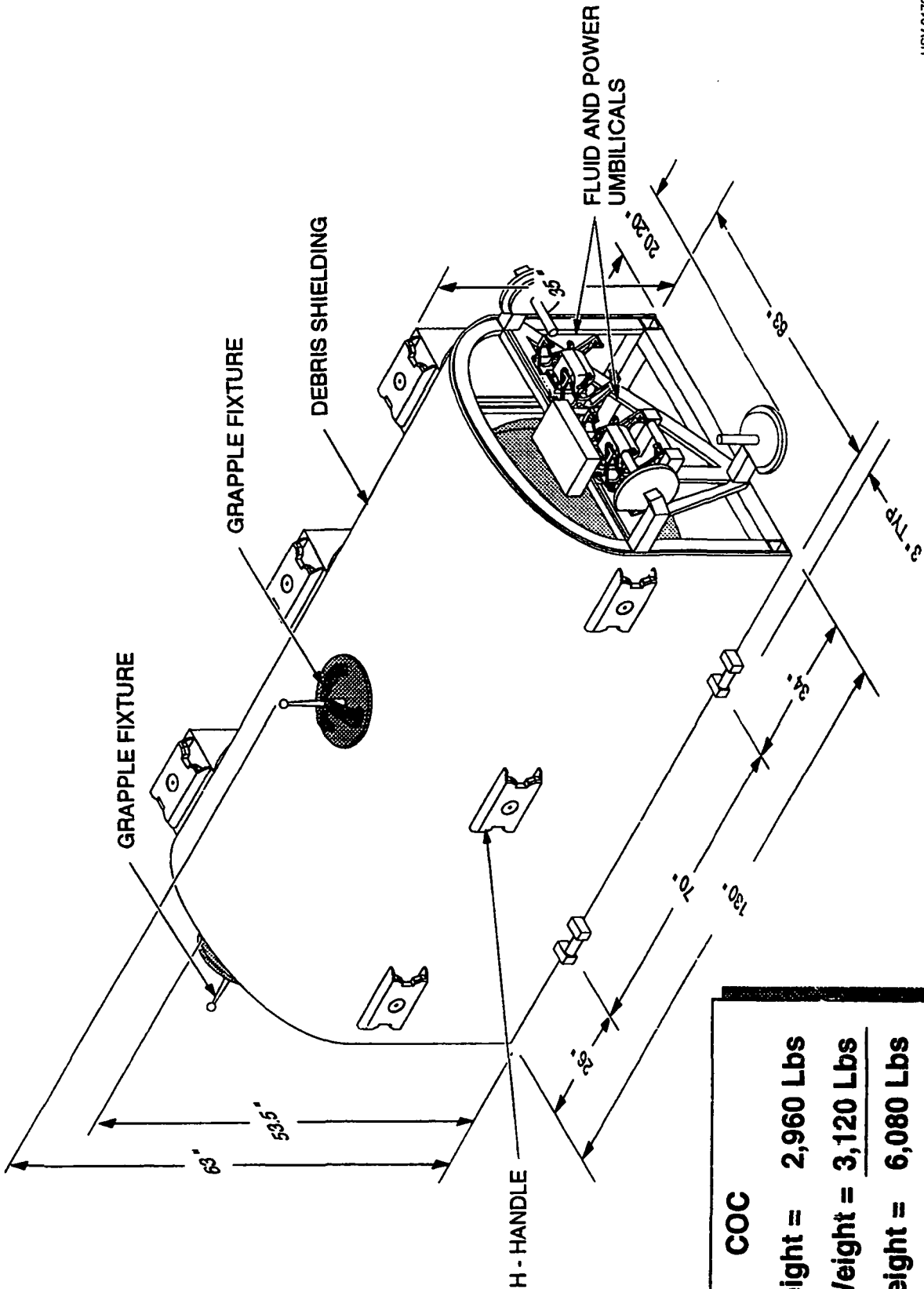
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Cryogenic Oxygen Carrier (COC)

Preliminary Configuration

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COC

Tare Weight = 2,960 Lbs
 Cargo Weight = 3,120 Lbs
 Total Weight = 6,080 Lbs

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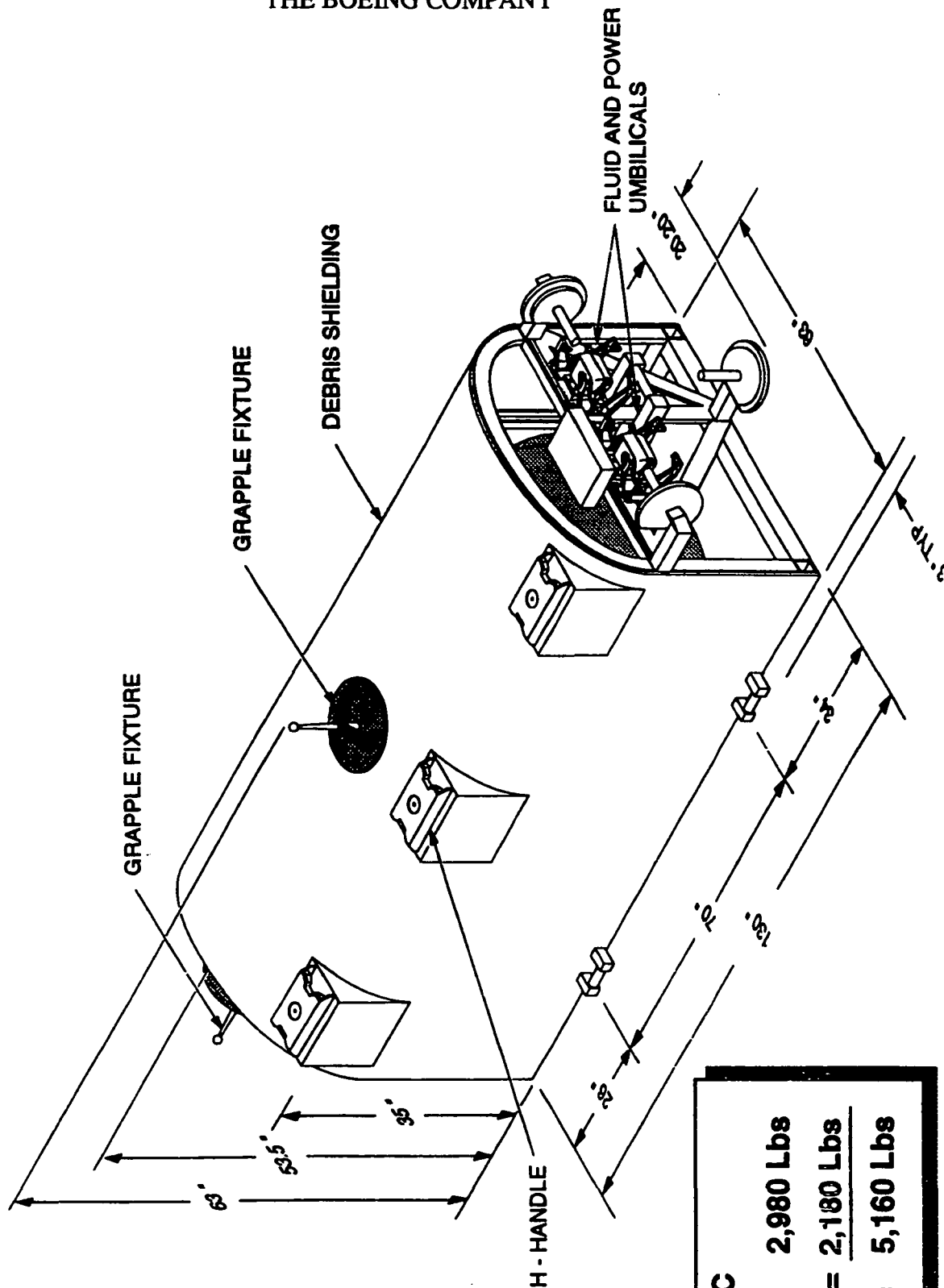
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Cryogenic Nitrogen Carrier (CNC) Preliminary Configuration

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HSV 0178



CNC	
Tare Weight =	2,980 Lbs
Cargo Weight =	2,180 Lbs
Total Weight =	5,160 Lbs

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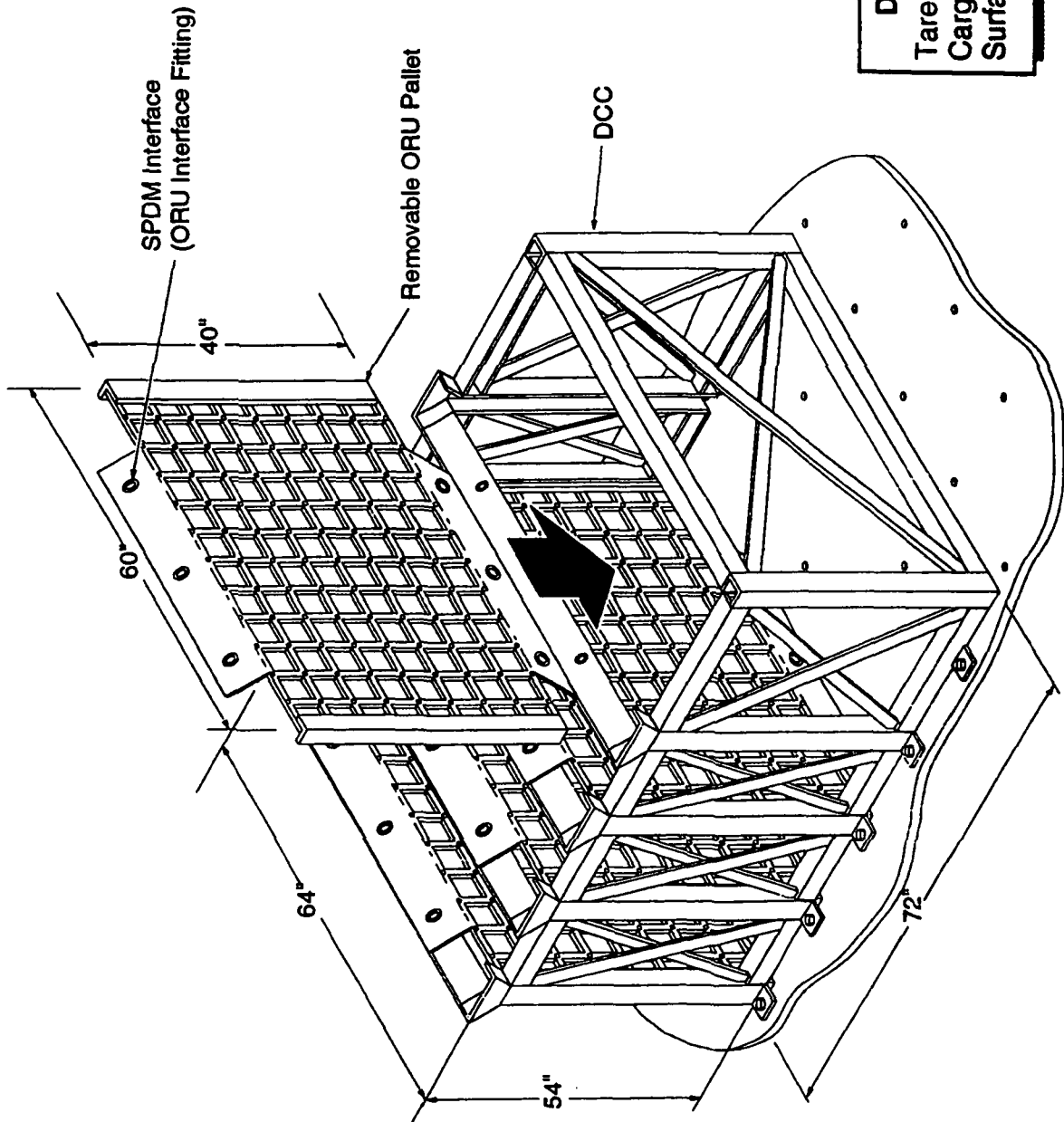
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Logistics Study/6-29-93/rfg

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DCC Configuration Preliminary Concept



DCC Characteristics	
Tare Weight	= 600 lbs
Cargo Capacity	= 2,000 lbs
Surface Area	= 2,400 in. ²

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Launch Vehicle Characteristics

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- STS/Titan IV/Ariane V Characteristics
- ELV Capability vs Logistics Carrier Weights
- Reference Mission Profile
- CTV Options
- Strongback Options

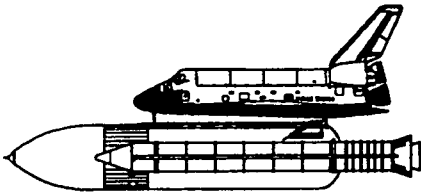
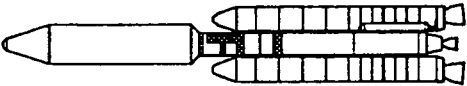
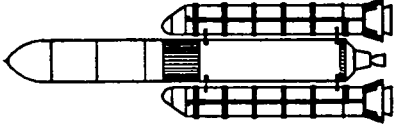
Launch vehicle performance is summarized here. The key performance parameters are: STS performance directly to SSF orbit (220 nmi), and ELV performance to 100 nmi. For ELVs, the CTV takes payloads from 100 nmi up to SSF orbit.

Load factors for both Titan and Ariane exceed those for STS as shown. For Titan, these higher load factors occur at engine shutdown from fuel or oxidizer exhaustion. If commanded shutdown is chosen, load factors are reduced to the range of STS load factors. Payload penalty for commanded shutdown is ~30 lbs fuel and oxidizer left over + ~5 lbs for low fuel/oxidizer sensors for a total of 35 lbs. We assumed essentially no difference between STS and ELV loads on the carrier concepts we examined at the level of detail of this study. Of course more detailed loads analyses would consider differences in value and orientation between the two classes of vehicles.

Launch Vehicle Characteristics

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	STS	Titan IV	Ariane V
			
CHARACTERISTICS			
Performance to 100 n.m. (185 km.); Circular; 28.5°	53,700 lbs (24,400 kg.) ⁽⁶⁾ 37,800 lbs (17,180 kg.) ⁽²⁾	39,100 lbs (17,700 kg.) 48,655 lbs (22,110 kg.) ⁽¹⁾	?? lbs (?? kg.)
P/L Dynamic Envelope	180 in. (472 cm.) x ⁽⁶⁾ 731 in (1,856 cm.)	180 in. (457 cm.) x ⁽⁶⁾ 480 in. (1,220 cm.)	180 in. (457 cm.) x ⁽⁵⁾ 480 in. (1,220 cm.)
Load Factors	+ 3.2 g axial ⁽⁶⁾ ± 2.5 g lateral	+ 4.5 g axial ⁽⁶⁾ ± 3.5 g lateral	+ 4.25 g axial ⁽⁵⁾ ± 2.0 g lateral
CTV Weight	NA	20,062 lbs ⁽³⁾ (9,118 kg.)	13,342 lbs ⁽⁴⁾ (6064 kg.)

 1. Solid Rocket Motor Update
2. 220 nm. Circular; 28.5°

 3. BUS-1
4. Auto. Trans. Vehicle (ATV)

 5. Ariane V User's
Manual 3/91

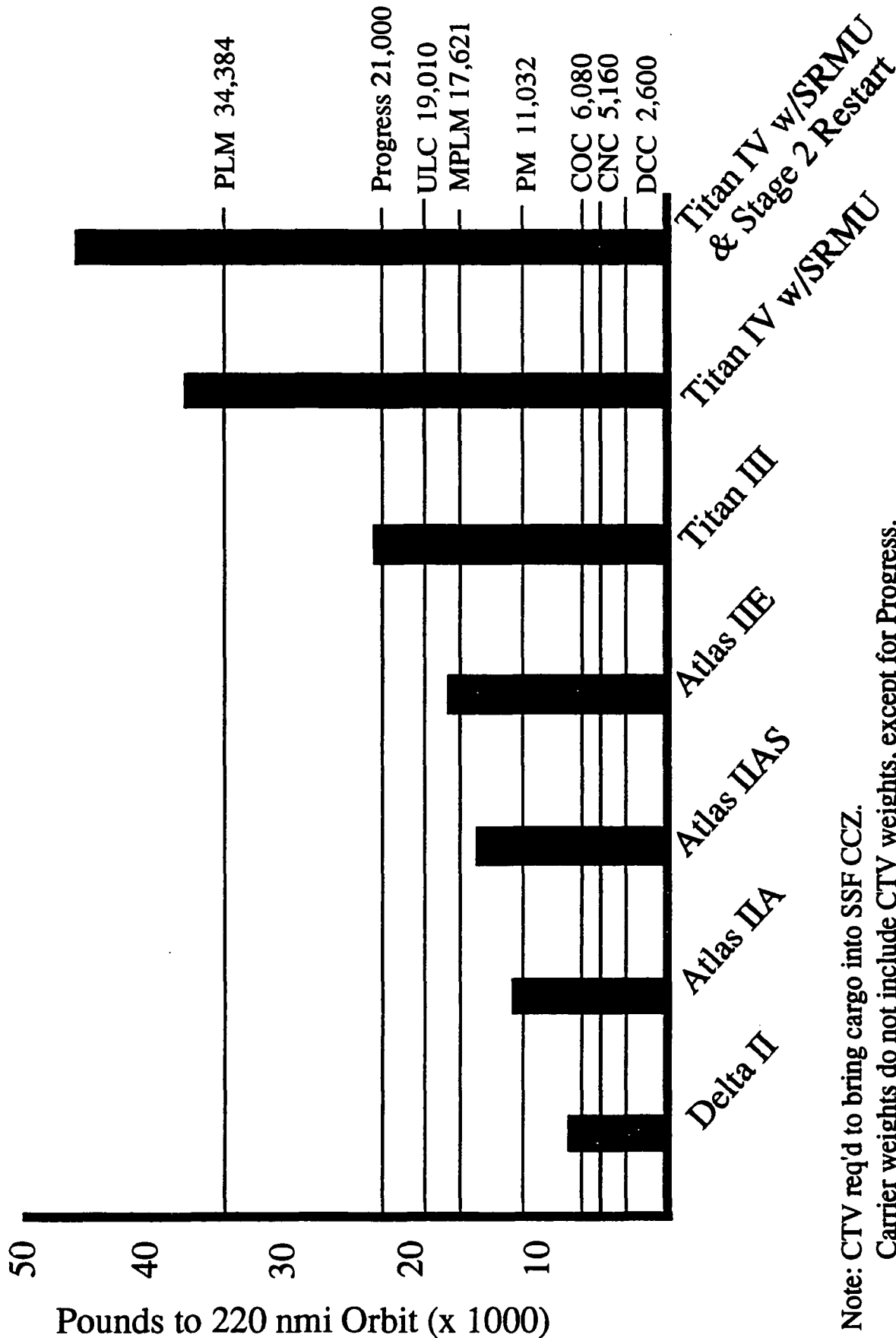
 6. AIAA International Reference Guide
to Space Launch Systems 1991 ed.

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ELV Capability Versus Logistics Carrier Weights

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Note: CTV req'd to bring cargo into SSF CCZ.

Carrier weights do not include CTV weights, except for Progress.

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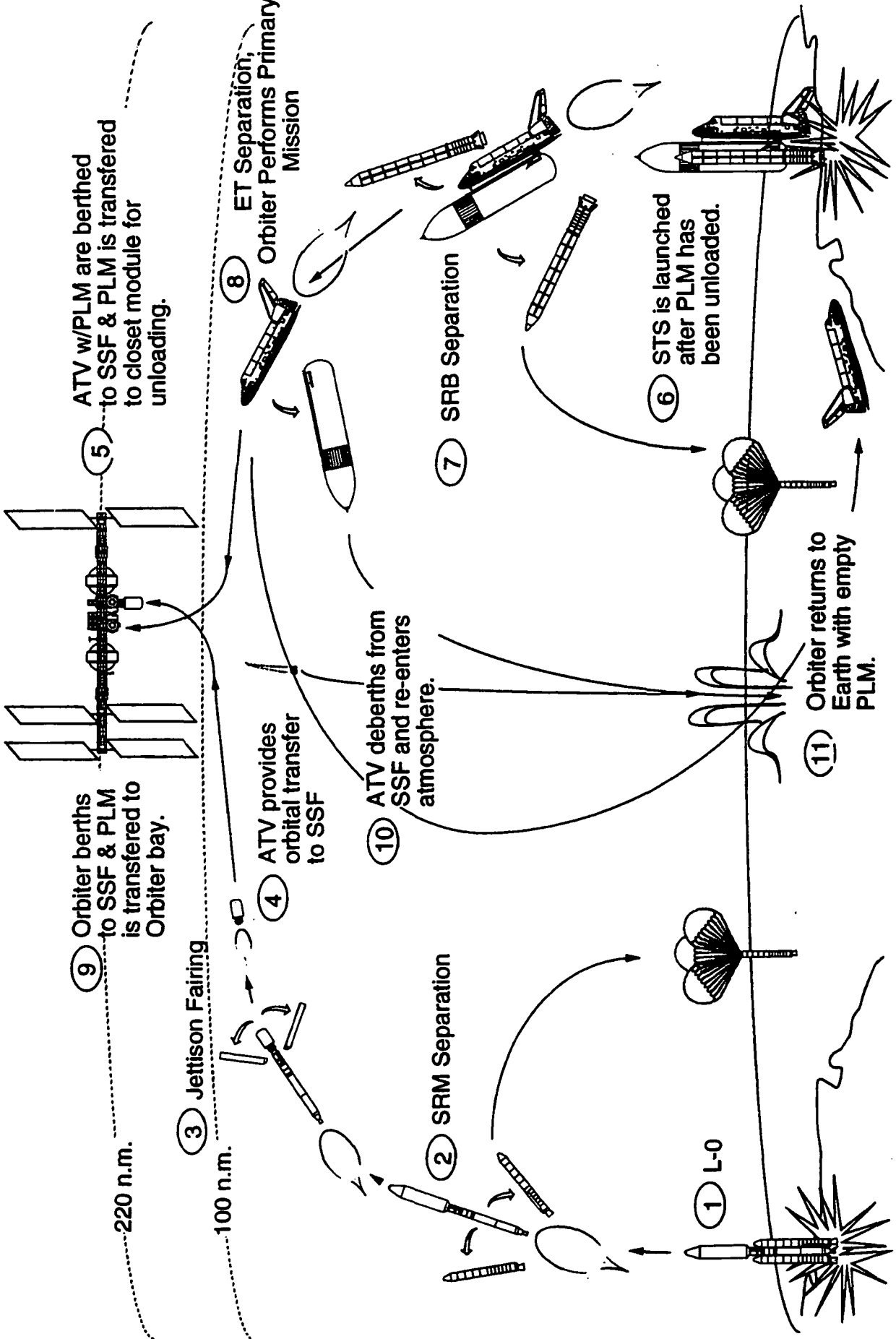
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This chart describes a reference mission scenario for delivering logistics elements to SSF on an ELV and returning them on STS. For long delays between ELV and STS flights, logistics elements may have to be moved on SSF to a temporary storage location.

ELV/STS Reference Mission Profile

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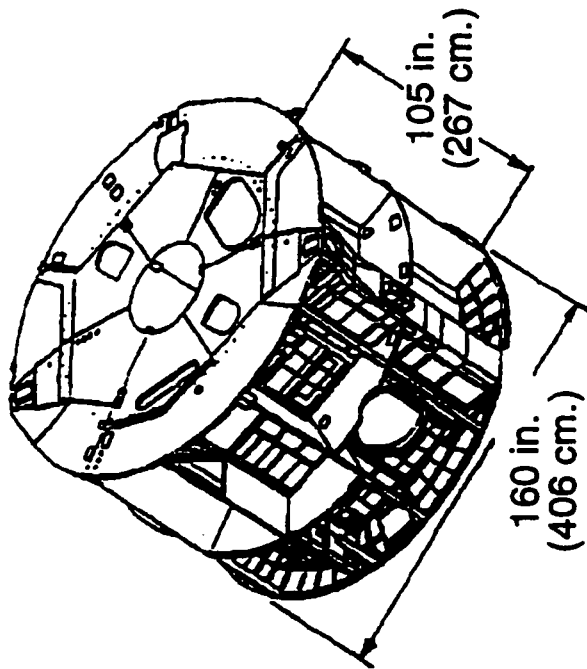
A CTV carries payloads from 100 nmi, where the ELV releases its cargo, to 220 nmi SSF orbit. We did not trade between these options, but used the ATV in most of our analyses because its cargo capacity was closer to the range in which we were working.

Cargo Transfer Vehicle Options

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BUS-1



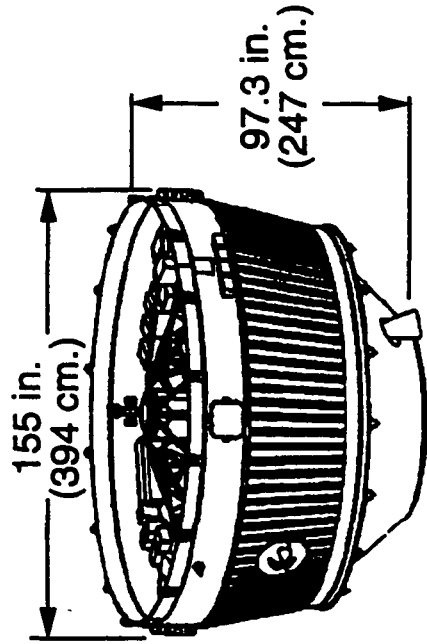
Cargo Capability: 50,000 lbs (22,727 kg.)
 Dry Weight: 6,562 lbs (2,982 kg.)
 Propellant Load: 13,500 lbs (6,136 kg.)
 TOTAL WEIGHT: 20,062 lbs (9,118 kg.)*

* MSFC provided data

** ESA ATV Executive Summary Document 12/15/92

U/018/CTV Options/Evans/3-16-93

AUTOMATED TRANSFER VEHICLE
(ATV)



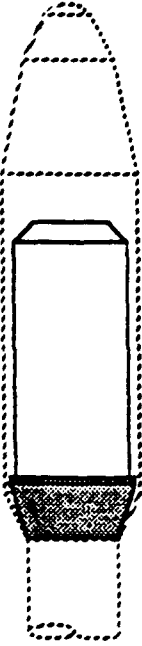
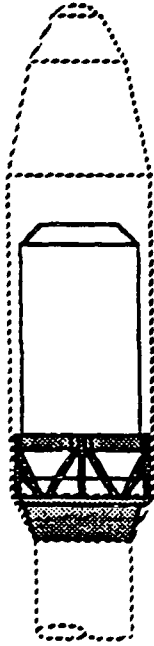
Cargo Capability: 32,000 lbs (14,500 kg.)
 Dry Weight: 6,478 lbs (2,944 kg.)
 Propellant Load: 6,864 lbs (3,120 kg.)
 TOTAL WEIGHT: 13,342 lbs (6064 kg.)**

Four strongback concepts are shown. Their sources are described below. We used concept (1) in most of our analyses. In order to fly STS compatible logistics carriers without modification on ELVs, a strongback providing equivalent trunnion and keel pin fitting interfaces is required. Use of a strongback will require either ELV shroud modifications (additional holes with aerodynamic covers to allow trunnion and keel pins, fittings, and interfacing structure to protrude) or a new, larger diameter shroud (with the exception of concept (4) below).

- (1) STS Compatible Payload Carrier is a MMC concept with a weight estimate of 4370 lbs as shown. This option was used in our studies most often because it was the only option available at the beginning of the study with a weight estimate.
- (2) Option 3: Shell Structure is a Boeing concept from last year's Evolution Study. Although conceived for an NLS-type vehicle, the concept of a semi-monocoque structure could apply to a Titan IV as well. No weight estimate was available.
- (3) The truss-type strongback shown is a Boeing concept also from last year's Evolution Study, also conceived for NLS. We shortened it for our application and reduced the initial weight estimate to the value shown.
- (4) The MDAC concepts shown are from several years ago. We emphasize the "Strongback Approach" concept, where the Titan shroud itself becomes a strongback, and STS-compatible payloads attach directly to the bottom half of the shroud using trunnion and keel pin fittings. The payload capability of 26-32K lbs (depending on atmospheric and trajectory assumptions) is the performance allocated to CTV plus actual payload (logistics carriers). The next chart describes structural details.

Payload Carrier Performance Summary Data

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CONCEPT	DATA USED FOR PERFORMANCE ESTIMATES
TITAN STANDARD PAYLOAD CARRIER 	• No Change to Fairing Weight • Carrier Dry Weight = 1140 lbs
TRUSS MOUNT PAYLOAD CARRIER 	• No Change to Fairing Weight • Carrier Dry Weight = 3193 lbs
STS COMPATIBLE PAYLOAD CARRIER 	• No Change to Fairing Weight • Carrier Dry Weight = 4370 lbs

MARTIN MARIETTA

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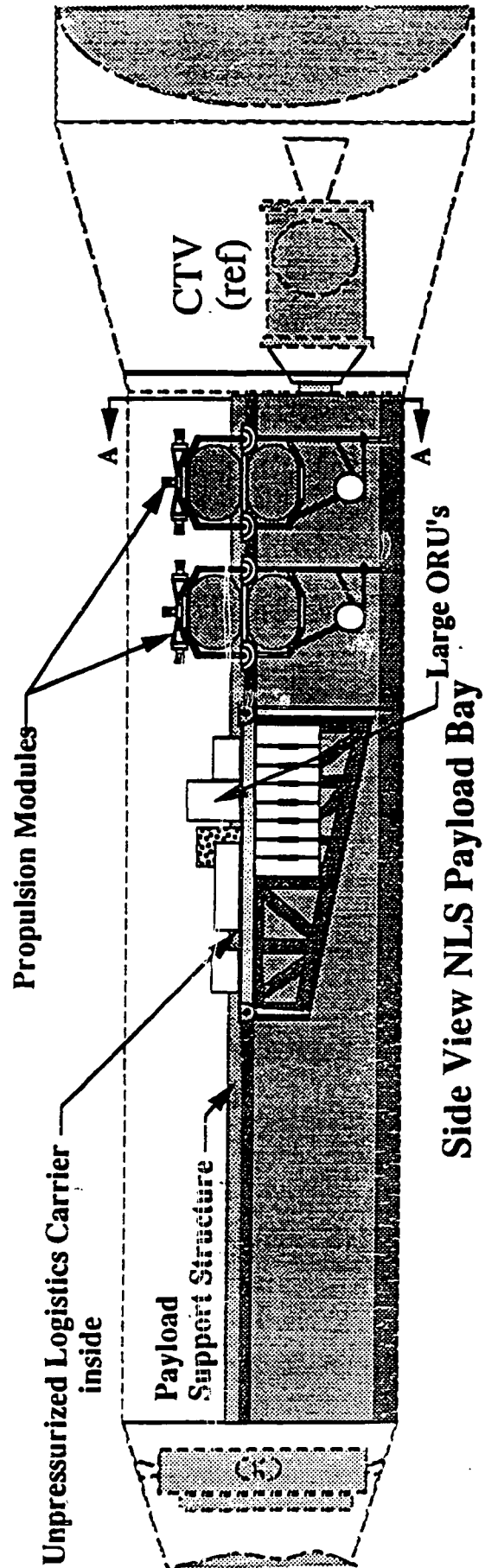
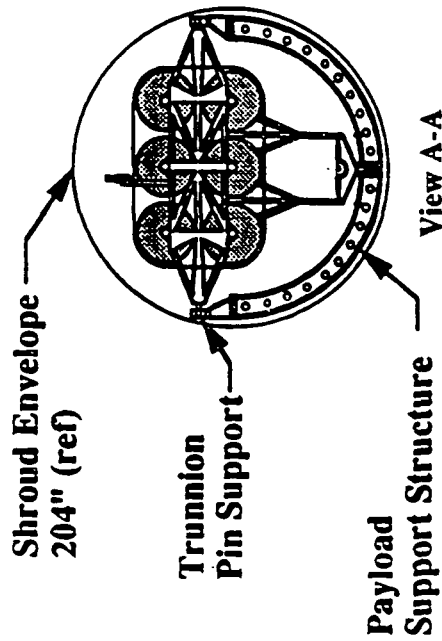
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Option 3: Shell Structure

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Option Attributes

- Semi-monocoque structure simulates STS cargo bay accommodations
- Payload Support Structure acts as on-orbit stowage structure
- NLS longérons and keel integral to Payload Support Structure
- Complete assembly is expendable



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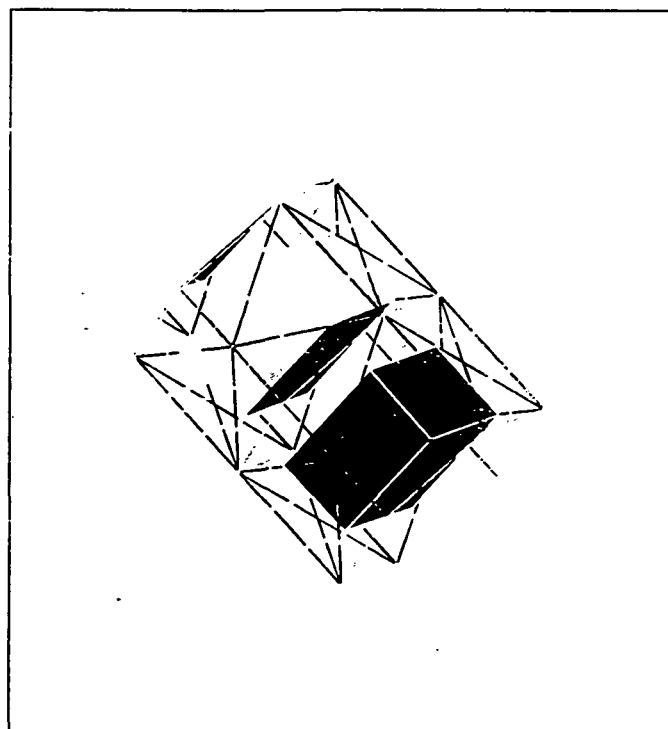
Strongback Concept

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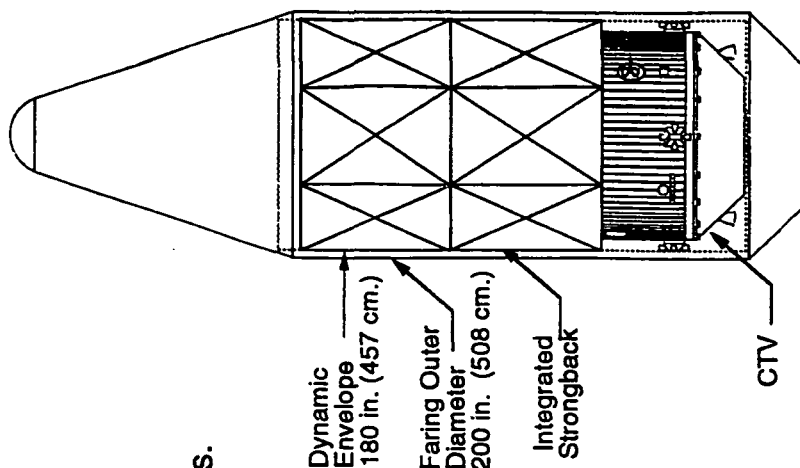
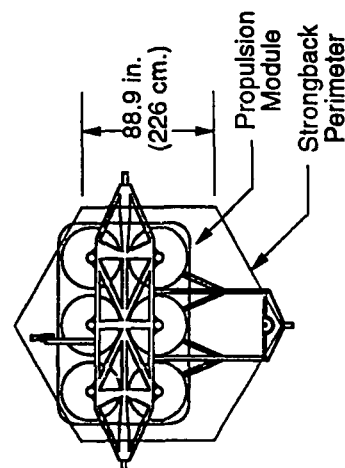
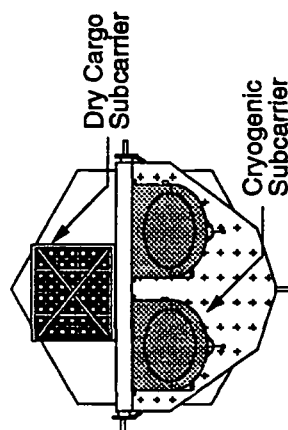
ISSUES

- Payload extraction on-orbit.
- Hard point attachment details.



CHARACTERISTICS

- Truss-type strongback structure shown above as optimized for distributed load.
- No modifications to STS-compatible carrier needed for launch on ELV.
- Option to retain STS return capability using shroud blisters around pins.



ELV Payload Bay

Mass Properties	
Tare Weight	1,700*
Cargo	16,300
TOTAL:	18,000

* Derived from NLS strongback analysis 9/2/92. Does not account for ancillary FSE.

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Titan IV Sized SSF Resupply Vehicles

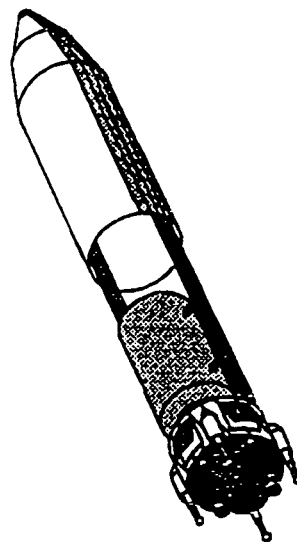
Payload Accommodations Compatible with STS Trunnion Mounted Payload Support System

MCDONNELL DOUGLAS

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KEY FEATURES:

- FULLY REUSEABLE
- RETURNS TO LAUNCH SITE
- HIGHLY OPERATIONAL
- CARGO RETURN CAPABILITY
- PAYLOAD MOUNTED TO BEAMS AND SHELL SLIDES OVER PAYLOAD
- NEW TITAN IV ADAPTER WITH AUTO CLEAT DESIGN

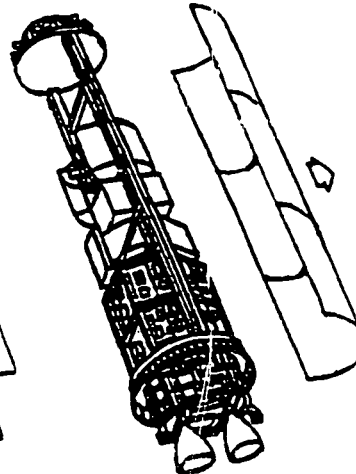
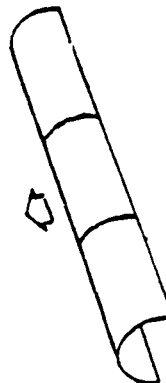


SLIDING SHELL APPROACH

PAYLOAD CAPABILITY
14-20 K

KEY FEATURES:

- REUSEABLE CTV
- EXPENDABLE CARGO CARRIER
- DE-ORBITS SSF TRASH
- PAYLOADS MOUNTED TO BEAMS AND SLID INTO SHELL
- SHELL JETTISONED POST MECO
- CONVENTIONAL CLEAT ATTACHMENT TO 2490 SKIRT

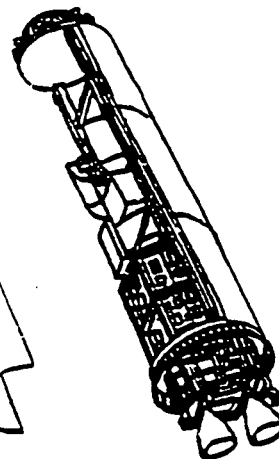
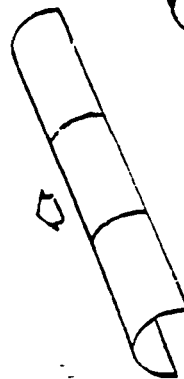


SLIDING BEAM APPROACH

PAYLOAD CAPABILITY
20-26 K

KEY FEATURES:

- REUSEABLE CTV
- EXPENDABLE CARGO CARRIER
- DE-ORBITS SSF TRASH
- PAYLOADS MOUNTED TO STRONGBACK
- SHELL HALF JETTISONED PRE MECO
- CONVENTIONAL CLEAT ATTACHMENT TO 2490 SKIRT



STRONGBACK APPROACH

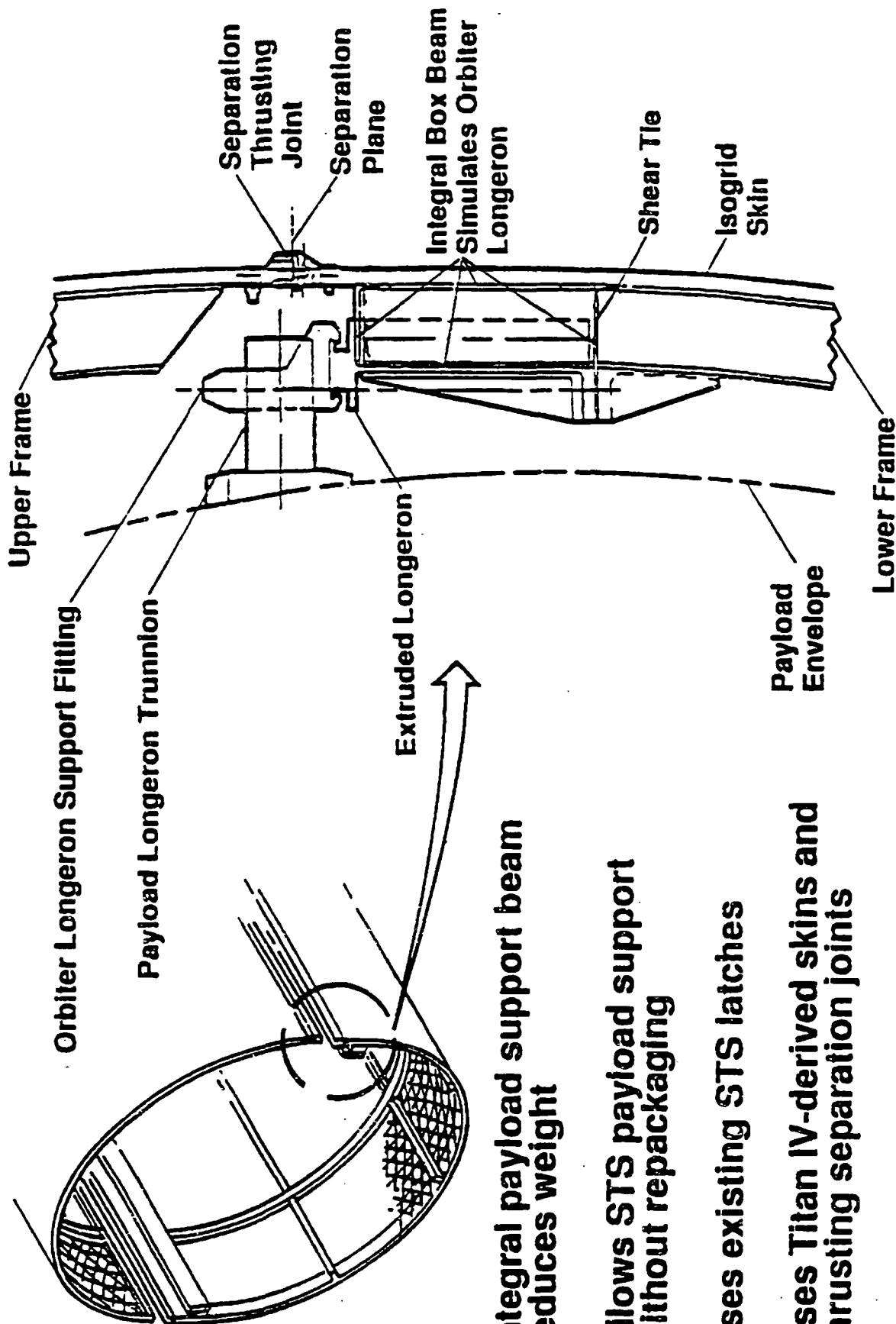
PAYLOAD CAPABILITY
26-32 K

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Integral Payload Support Beam Simulates Orbiter Longeron

VDD20176.2 T1EC

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- ☐ Integral payload support beam reduces weight
- ☐ Allows STS payload support without repackaging
- ☐ Uses existing STS latches
- ☐ Uses Titan IV-derived skins and thrusting separation joints

Logistics Study/6-29-93/rng

Two approaches were taken in this study. First, we looked at concepts for minimum mods to existing logistics carriers to adapt them for launch on an ELV and return on STS. The second time through, we looked at ways to modify carriers more significantly, or identify new carriers, for launch on ELV without return on STS. Logistics elements "optimized" for ELV launch must be either deorbited for destructive reentry, returned in another manner, or reused on-orbit. Pressurized carrier concepts in both categories are described below.

Pressurized Logistics Carriers

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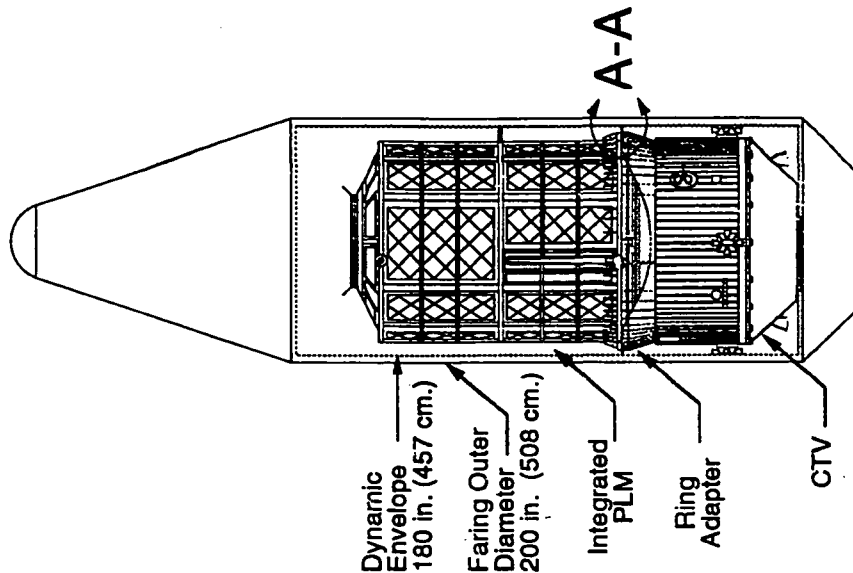
- Minimum Mods to STS-Compatible Carriers
 - End-Mounted PLM
 - End-Mounted MPLM
- ELV-Optimized Carriers
 - PLM with Late Access Panel
 - Spacehab on ELV

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End-Mounted PLM

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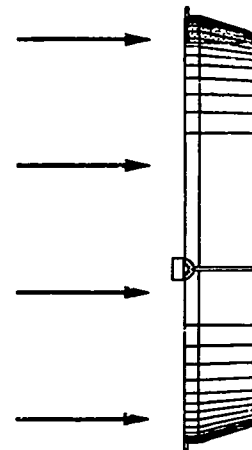
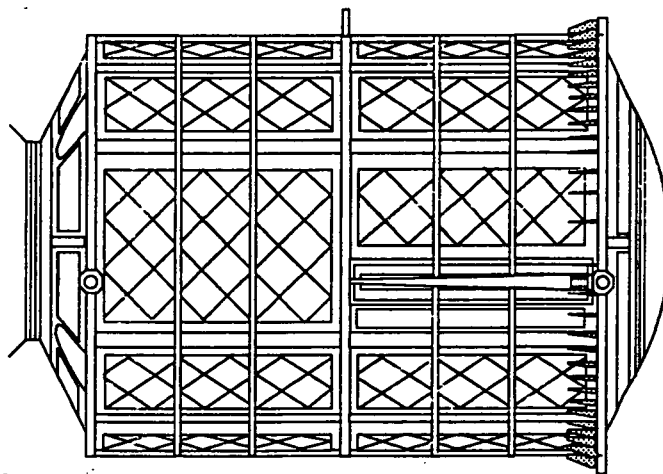
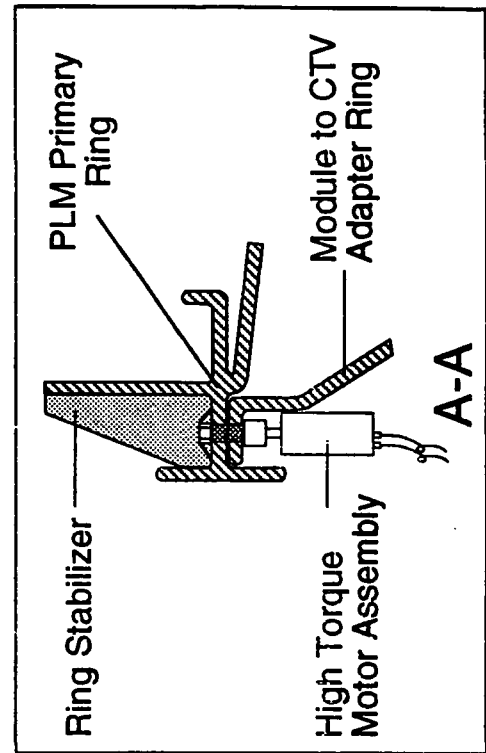


ELV Payload Bay

Mass Properties	
Tare Weight	11,498
Cargo	22,886
Modifications	195
TOTAL:	34,579

CHARACTERISTICS

- PLM mounted longitudinally in ELV shroud
 - PLM to CTV Adapter
 - Adapter attaches to PLM primary ring
- PLM modifications
 - Main ring strengthening: 175 lbs
 - Ring stabilizing gussets: 20 lbs
- STS return capability retained
 - Trunnion/keel Pins installed on-orbit, or
 - Shroud blisters around pins
- Late access through shroud/hatch
- Power from CTV and/or batteries in adapter
- Cooling from Body Mounted Radiators



Adapter Ring:
O.D. = 170 in. (431 cm.)
Length = 28 in. (71 cm.)

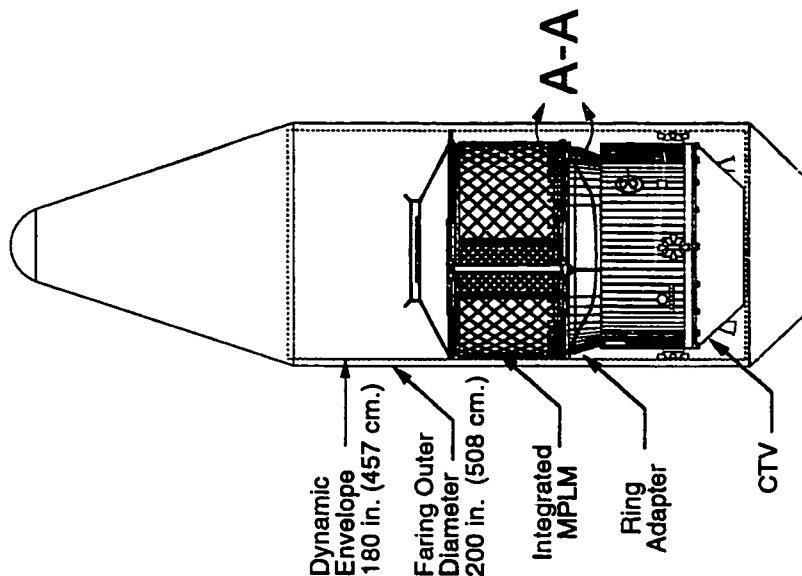
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End-Mounted MPLM

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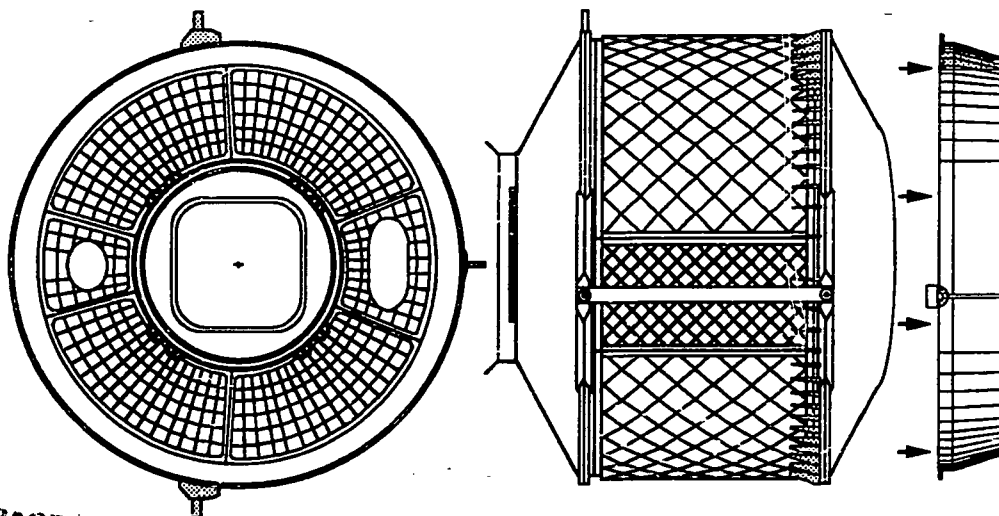
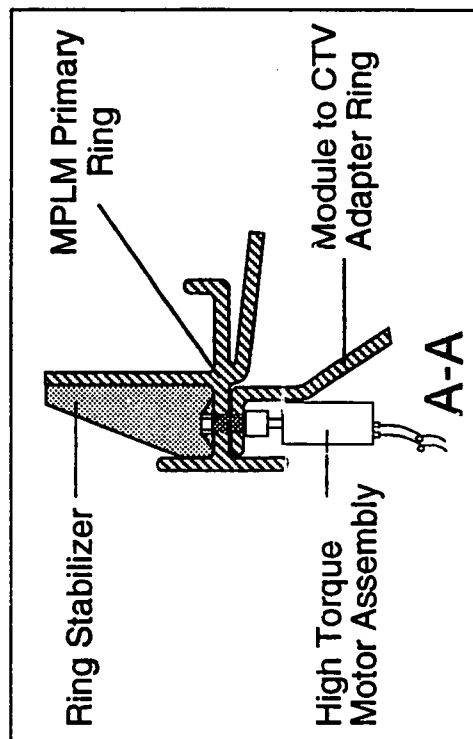


ELV Payload Bay

Mass Properties	
Tare Weight	8,346
Cargo	9,275
Modifications	195
TOTAL:	17,816

CHARACTERISTICS

- MPLM mounted longitudinally in ELV shroud
 - MPLM to CTV Adapter
 - Adapter attaches to MPLM primary ring
- MPLM modifications
 - Main ring strengthening: 175 lbs
 - Ring stabilizing gussets: 20 lbs
- STS return capability retained
 - Trunnion/keel Pins installed on-orbit, or
 - Shroud blisters around pins



Adapter Ring:
O.D. = 170 in. (431 cm.)
Length = 28 in. (71 cm.)

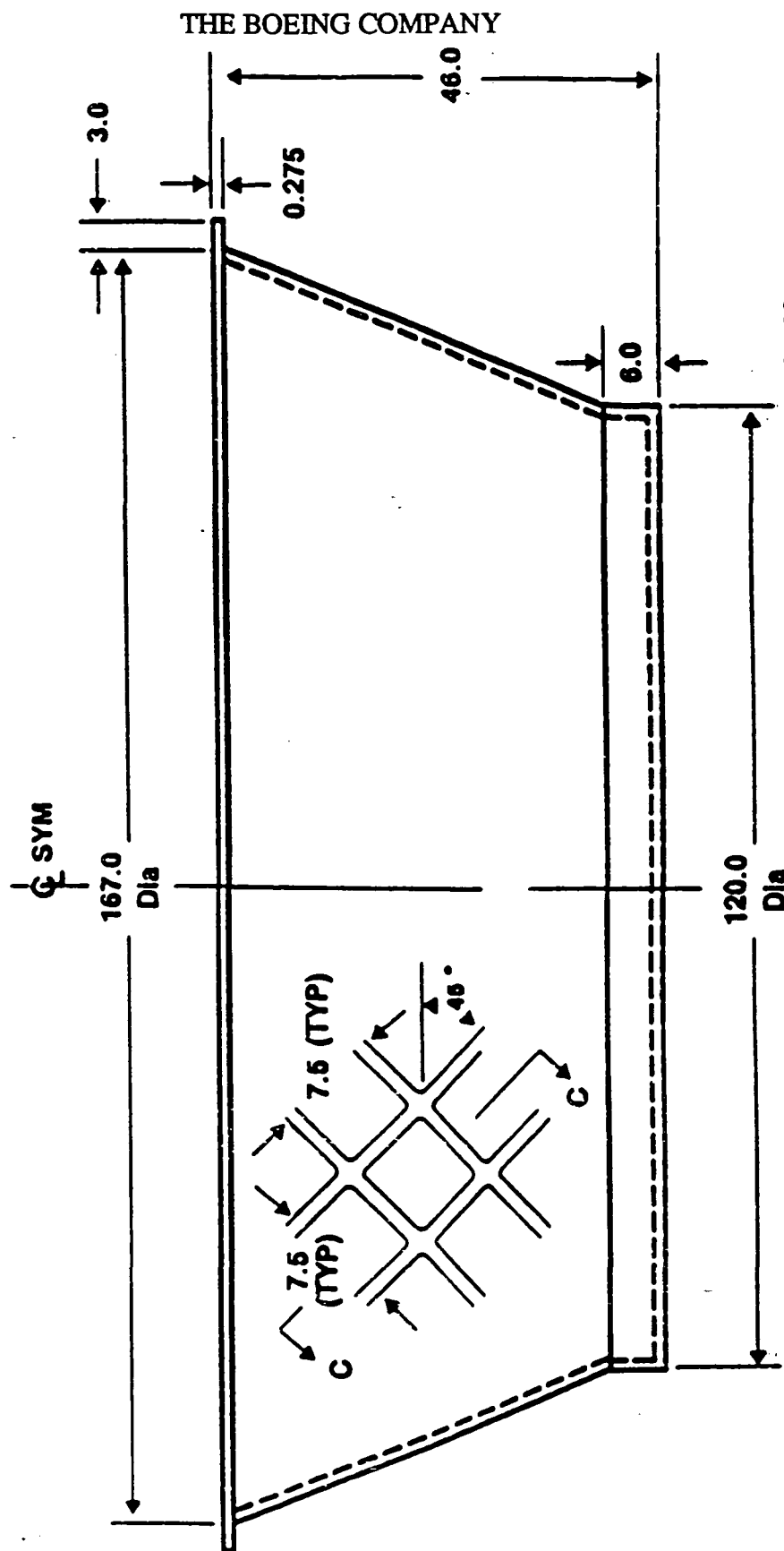
The following nine charts describe modifications to the PLM/MPLM required for flight on an ELV.

An adapter structurally connecting the PLM to the CTV is required. The configuration shown was conceptualized during Boeing SSF Phase B studies. A weight trade was conducted and the wafflegrid structure had the lowest weight at 780 lbs. During the current study, several more adapters were conceptualized to attach different logistics carriers to a CTV. They were all based on this concept, but not all were weighed. When a weight was not available, the weight estimate for this adapter was used. The same adapter was used for both PLM/MPLM in this study.

Logistics Resupply - STS/ELV Dual Compatibility

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Payload Adaptor Configuration


NOTES:

- 1 ASSY - MONOCOQUE
- 2 ASSY - WAFFLEGRID

Two Configurations
Monocoque
Wafflegrid

All dimensions in inches
2219-T87 ALUM

Seventy-two gusset stabilizers were added to the PLM aft ring where the adaptor attaches. This Phase B chart did not show a payload de-couple, or separation, system. A separation system concept defined in the current study is shown in the next chart. The separation system would be actuated by a CTV command.

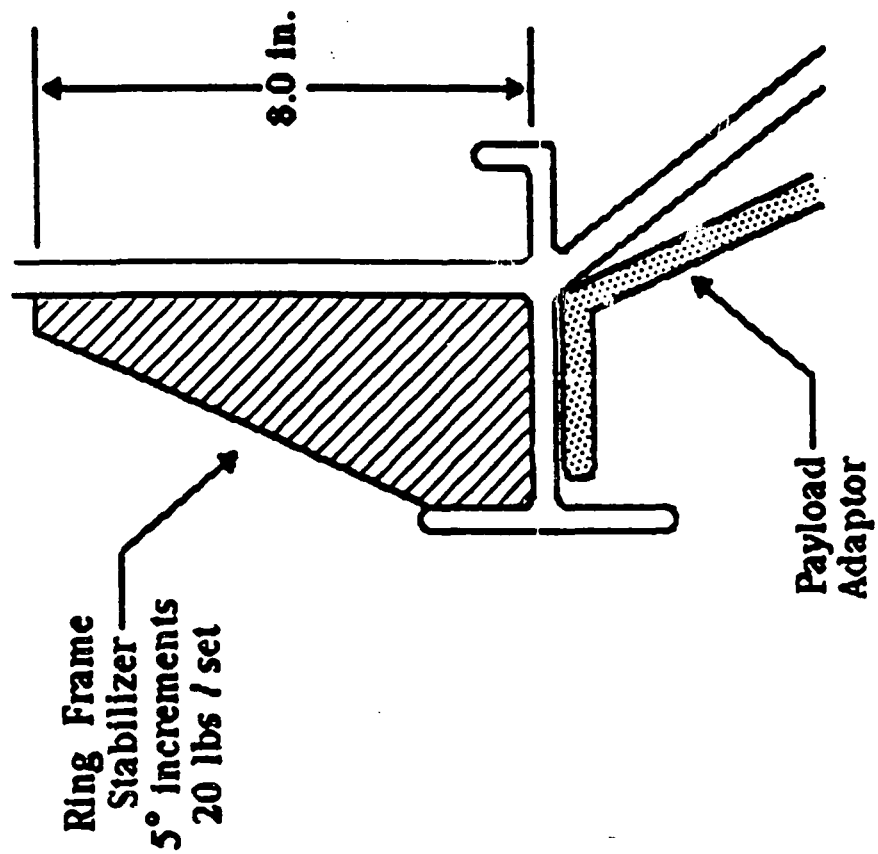
Logistics Resupply - STS/ELV Dual Compatibility

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Module Modification

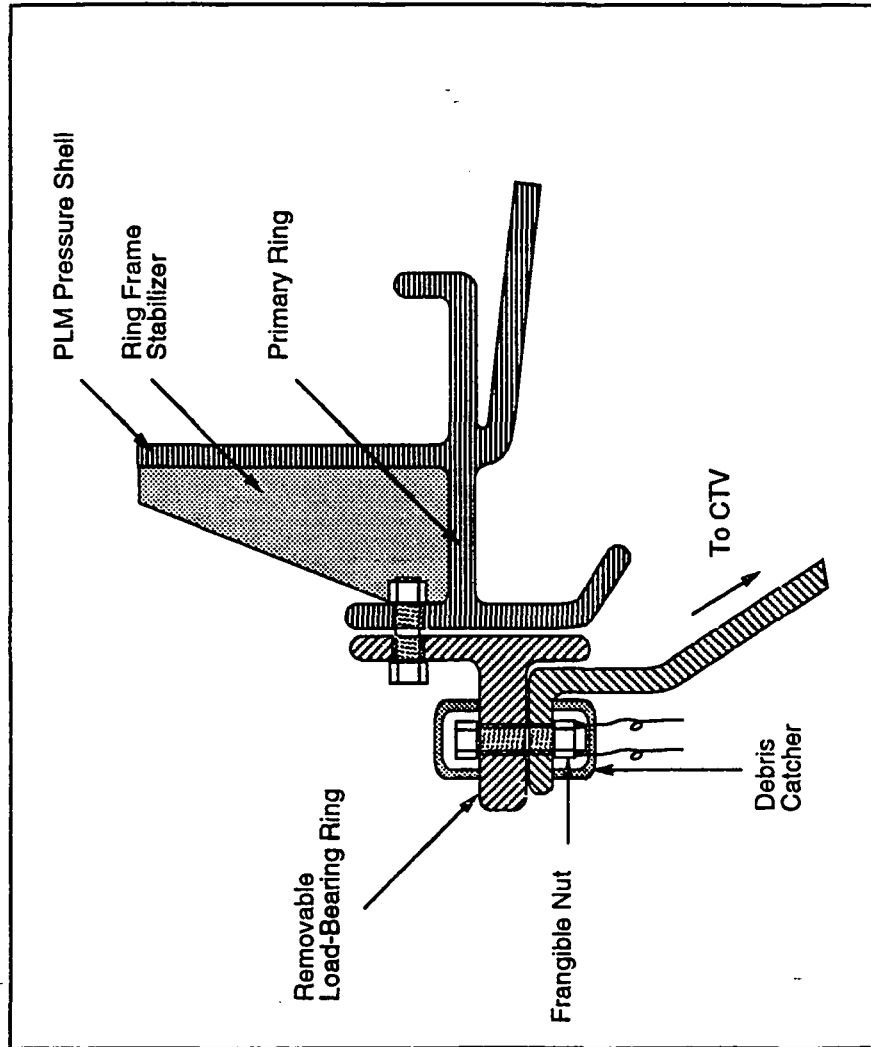
- Stabilize aft ring frame
- Design payload de-couple system



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CTV/PLM Separation System Concept

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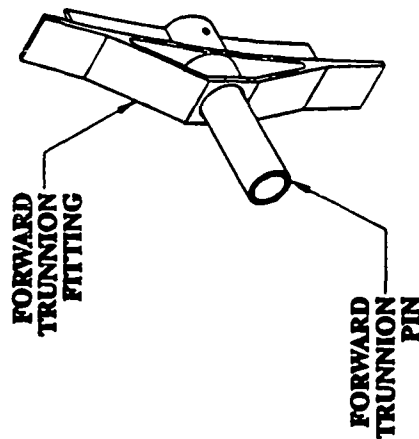


As described in the previous End-Mounted PLM concept chart, trunnion and keel pins on the PLM/MPLM will exceed the 180" diameter dynamic envelope of a Titan IV or Ariane V ELV (installed pins yield payload diameter of 195.5"). In order to launch on an ELV and return on STS, either the pins will have to be taken out and reinstalled on-orbit, or left in and holes cut in the ELV shroud. The pins are designed to be installed into their fittings by interference fit and secured with a fastener. On the ground this is done by cooling the pins before installation. This technique appears feasible on-orbit but would complicate the process of readying the PLM/MPLM for return in the Orbiter.

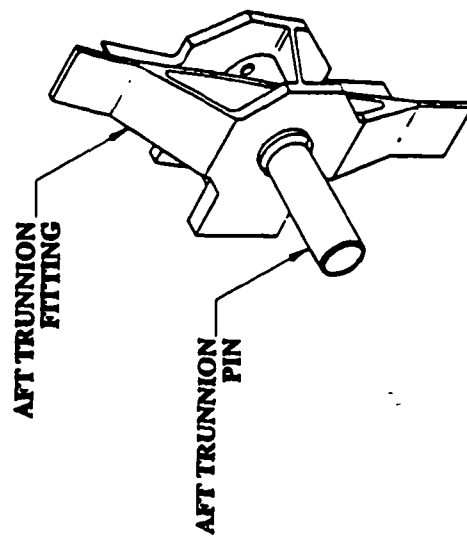
Lab 'A' MTC PDR Primary Structure

BOEING

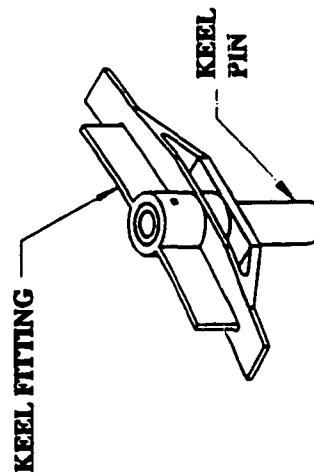
Trunnion and keel pins provide interfaces with the NSTS and create a five-point retention system (indeterminate system)



**STABILIZING FITTING
REACTS VERTICAL LOADS (F_z)**



**PRIMARY FITTING
REACTS LONGITUDINAL (F_x)
& VERTICAL LOADS (F_z)**



**AUXILARY FITTING
REACTS SIDE LOADS (F_y)**

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Power and cooling will have to be provided to the PLM/MPLM during launch and transfer to SSF. The ATV provides up to 500W to the payload, but the PLM/MPLM will require more power and liquid cooling. For purposes of sizing, a load of 1875W (MPLM with 1 system rack and 7 refrigerator/freezer racks) was used. Calculations for providing these resources are shown in the following charts. It is envisioned that the batteries (or fuel cells) would be located inside the CTV/PLM adapter. Body-mounted radiators would be located on the cylindrical surface of the PLM/MPLM.

The following two charts describe a concept for providing only the 500W the ATV is designed to provide to the payload. Note that even with this lower level of power, liquid cooling would still have to be provided to the PLM/MPLM.

Zn/AgO Batteries

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ASSUMPTIONS

- Batteries provide needed MPLM power during CTV orbit transfer.
 - Fuel cells offer potential mass savings.
- MPLM average power requirement of 1875 W, 120V during CTV orbit transfer with 7 refrigerator/freezer racks, 1 system rack.
- Logistics carrier application options
 - Carrier provided kit
 - CTV designed-in capability
 - CTV-provided kit

CALCULATION

- Silver-Zinc (Zn/AgO) batteries lowest mass for this application.
- MPLM load of 1875 W for 48 hours nominal transfer mission.
- Yardney PML400 battery (space qualified) provides 48,000 Whr at 540 lbs and 3.3 ft³ each.
- Total energy required: $(1875 \text{ W})(48 \text{ Hr}) = 90,000 \text{ Whr}$
- Number of batteries required: $(90,000 \text{ Whr}) / (48,000 \text{ Whr/battery}) = 2 \text{ bat.}$
- Weight of batteries: $(2)(540 \text{ lbs}) = 1,080 \text{ lbs}$
- Volume of batteries: $(2)(3.3) = 6.6 \text{ ft}^3$
- 4 batteries required for 48 hours plus additional 40 hours standoff capability yielding 2,160 lbs and 13.2 ft³

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Fuel Cells

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ASSUMPTIONS

- Fuel Cells provide needed MPLM power during CTV orbit transfer.
- MPLM average power requirement of 1875 W, 120V during CTV orbit transfer with 7 refrigerator/freezer racks, 1 system rack.
- Logistics carrier application options
 - Carrier provided kit
 - CTV designed-in capability
 - CTV-provided kit
- Use existing STS fuel cells/tankage designs

CALCULATION

- MPLM load of 1875 W for 48 hours nominal transfer mission.
- Total energy required: $(1875 \text{ W})(48 \text{ Hr}) = 90,000 \text{ Whr}$.
- Weight of fuel cell system: 990 lbs. (four fuel cells plus tankage)
- Weight of fuel cell system with additional 40 Hr standoff capability: 1,034 lbs. (includes additional LO_2/LH_2)
- Volume of fuel cells: Cells: 7.5 ft.³; Tankage: 24.7 ft.³ (same for both 48 & 88 hr option).

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Body Mounted Radiators

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ASSUMPTIONS

- BMR performance for MPLM is similar to BMR performance for HAB, USL, Nodes from WP01.*
 - 4067 ft² rejecting 36.1 KW for 6305 lbs yields 8.9 W/ft² and 5.7 W/lb.
- BMRs based on heat pipe technology, silverized teflon coatings.
- MPLM average power requirements of 1875 W during CTV orbit transfer with 7 refrigerator/freezer racks, 1 system rack.

CALCULATION

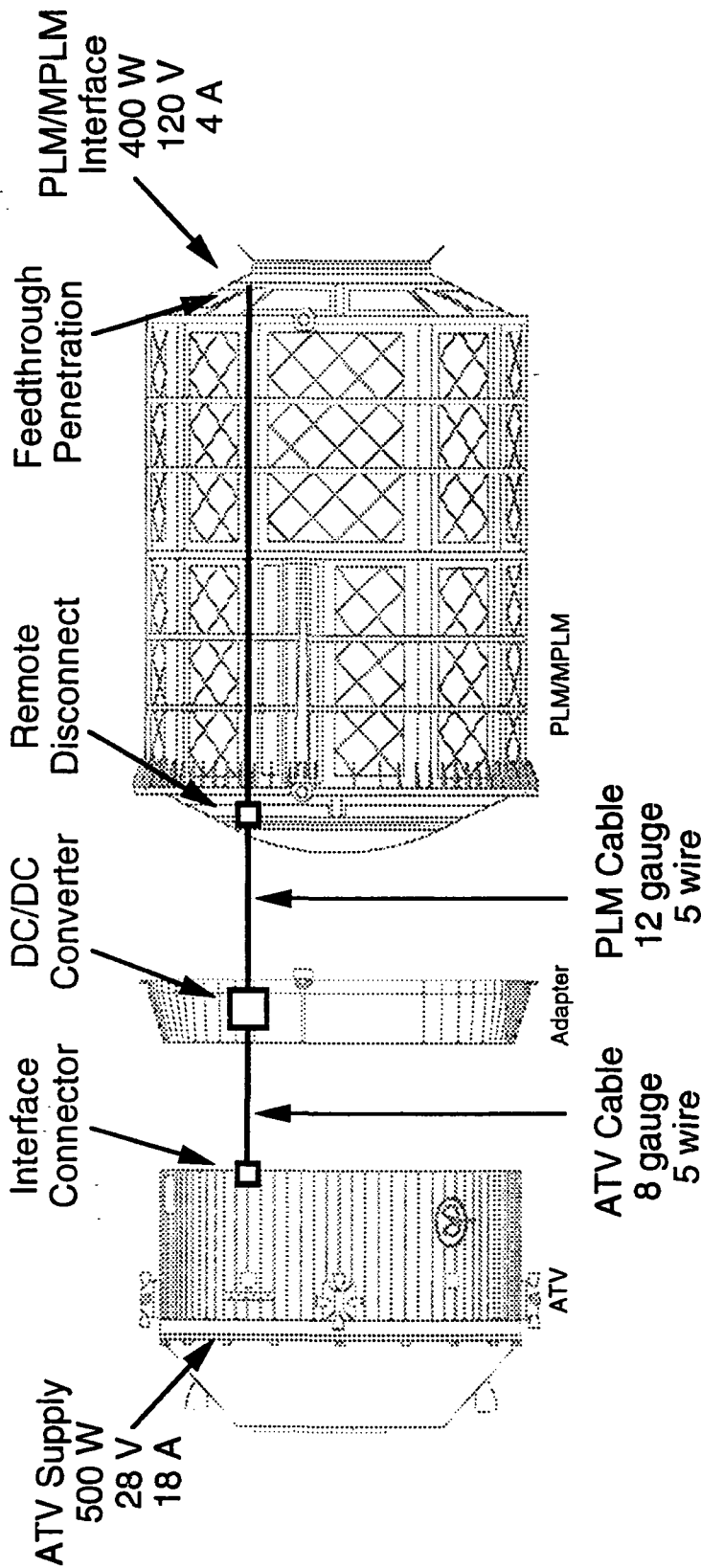
- BMR for load of 1875 W yields 211 ft (of 414 ft² available on MPLM) and 329 lbs

* 1989 TCS BMR study package

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ATV Power to PLM/MPLM Concept Sketch

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- Automated Transfer Vehicle (ATV) provides power to PLM/MPLM payload *
- During orbit transfer from ELV release until rendezvous with SSF
- 500W, 28V converted to 120V
- Wires external to pressurized environment
- Remote disconnect controlled by ATV
- Weight estimate 90 lbs

* Nominal power requirements for PLM/MPLM are 1339/997W during ascent, and if powered to this level requires fluid flow for cooling

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ATV Power to PLM/MPLM (cont)

Concept Sketch

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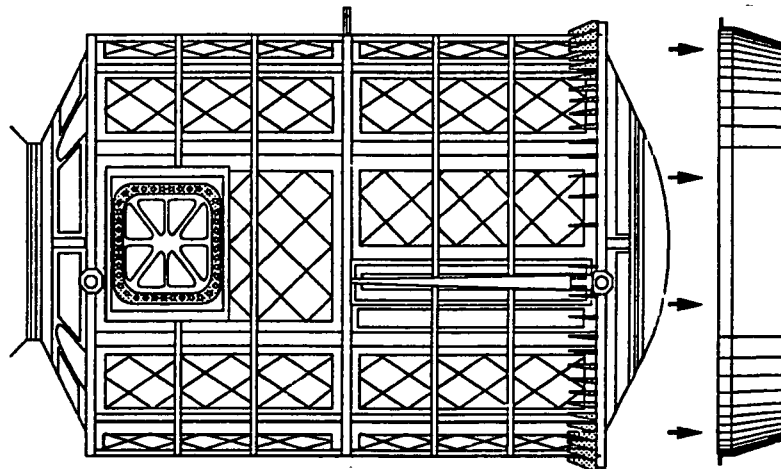
Item	Weight	Comments
ATV Interface Connector	2 lbs	Unknown type
ATV Cable	8	0.15 lb/ft x 10 ft x 5 wires; runs internal to ATV/Adapter shell (3 wires for power, 2 wires for remote disconnect)
DC/DC Converter	50	Converts 28V to 120V (80% efficiency); est 8x8"; rad cooled (WP02 Aux Power Conversion Unit (APCU-B), rad cooled, 1 kW, 100 lbs)
PLM Cable	10	0.05 lb/ft x 40 ft x 5 wires; penetration at Adapter shell; runs under PLM M/D shield, MLI (3 wires for power, 2 wires for remote disconnect)
Remote Disconnect	10	Remote disconnect device for Adapter/PLM separation, controlled by ATV
PLM Feedthrough Penetration	--	PLM cable wired directly to feedthrough
<u>Bracketry</u> Total	<u>10</u> 90 lbs	Converter, cable support

The next two charts illustrate concepts for pressurized carriers optimized for ELV launch. PLM with Late Access Panel and Spacehab on ELV are conceptualized to ease the late access problem with a vertically installed PLM/MPLM on an ELV. Access panel is sized to allow rack-sized items to pass.

PLM with Late Access Panel

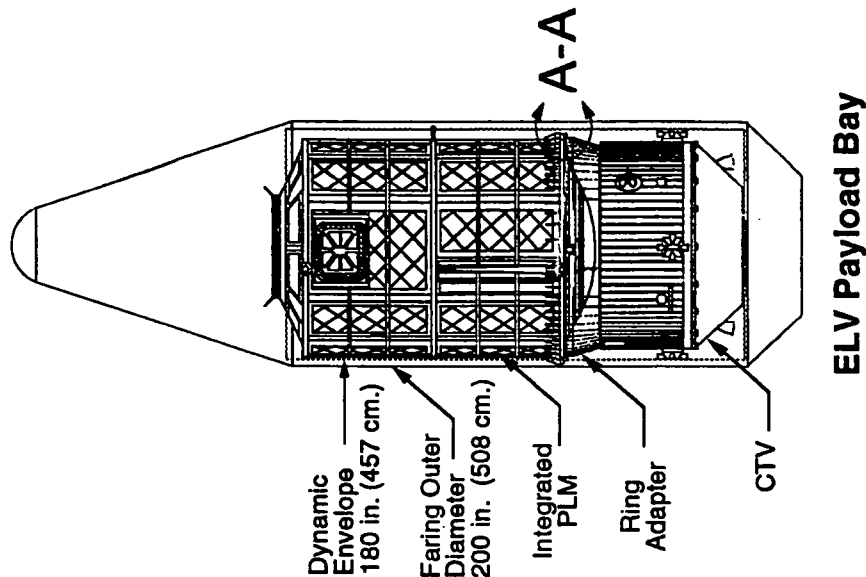
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CHARACTERISTICS

- PLM mounted longitudinally in ELV shroud
 - PLM to CTV Adapter
 - Adapter attaches to PLM primary ring
- PLM modifications
 - Access panel 40 x 42 in. (102 x 107 cm.)
 - Soft stowage inside of access panel replaces rack displaced by panel.
- PLM access panel requires a shroud panel of equal or greater dimensions.
- Simpler GSE than vertical access



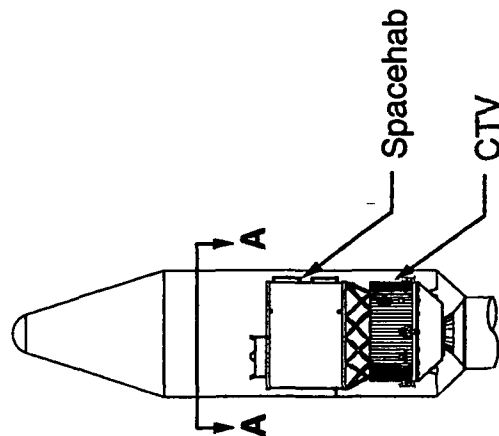
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Spacehab on ELV

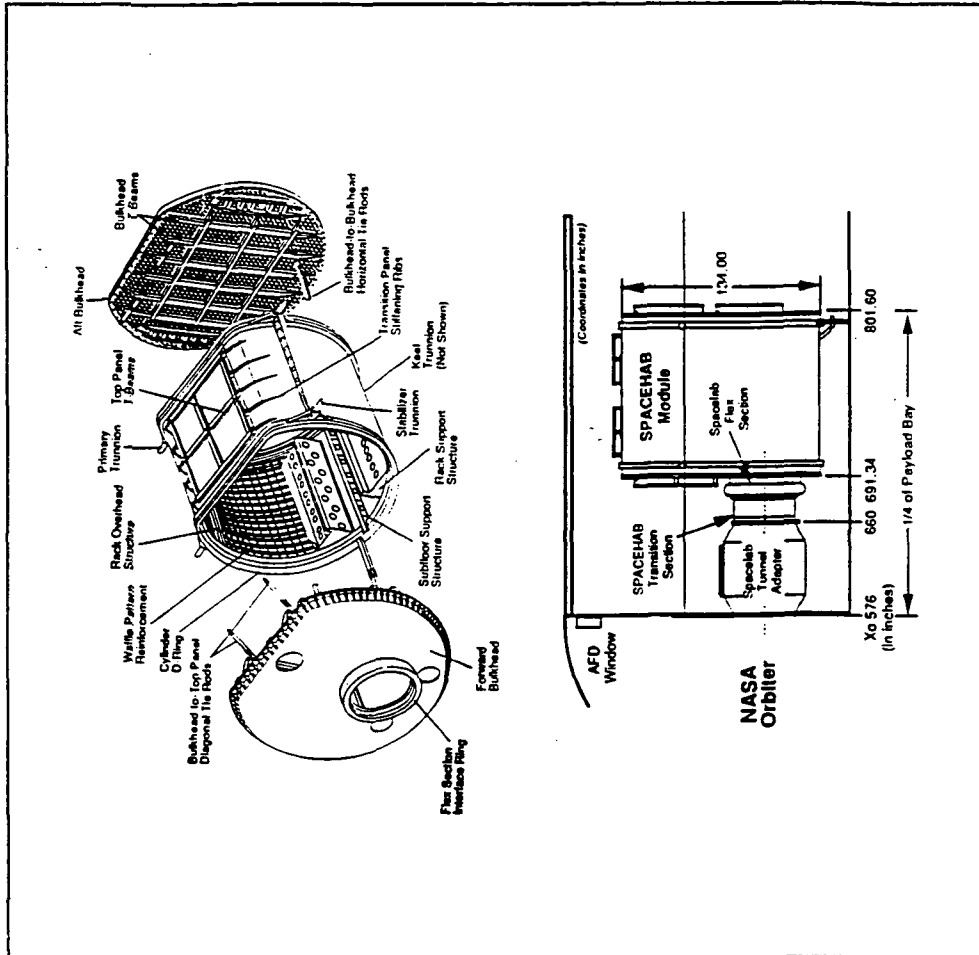
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CHARACTERISTICS

- Spacehab provides accessible space on ELV for late access cargo.
 - Horizontal access through new hatch on flat radial surface.
- Spacehab adapted for launch on ELV.
 - Truss adapter for end-mounting.
 - Hatch for late access through shroud.
- Current Spacehab on STS.
 - 625 W payload provided power during ascent.
 - 1100 ft³ (71 locker equivalent)
 - Tare Weight: 10,194 lb.
 - Maximum payload weight: 3000 lb.



**Titan IV
Faring Section**



ISSUES

- Development status of Spacehab modifications to berth at SSF.
- New hatch for horizontal access on launch pad.

The next section describes unpressurized logistics carrier concepts defined during the two portions of this study, (1) concepts for minimum mods to existing carriers to adapt them for launch on an ELV and return on STS, and (2) ways to modify carriers more significantly, or identify new carriers, for launch on ELV without return on STS. Logistics elements "optimized" for ELV launch must be either deorbited for destructive reentry, returned in another manner, or reused on-orbit. Unpressurized carrier concepts in both categories are described below.

Unpressurized Logistics Carriers

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- Minimum Mods to STS-Compatible Carriers
 - End-Mounted ULC
 - Strongback-Mounted ULC
 - Strongback-Mounted PM
- ELV-Optimized Carriers
 - Shroud Chamber ULC
 - End-Mounted PM
 - "Edible" ULC/Racks
 - Triangular Beam ULC
 - Cruciform ULC
 - Atlas IIA-Launched ULC
 - Progress-Delivered ULC
 - Stacked Triangular Beam ULC

We identified concepts for flying a ULC both end-mounted and installed in a strongback. We felt the end-mounted ULC concept could be accomplished with "minimum mods". The strongback option requires a larger diameter ELV shroud.

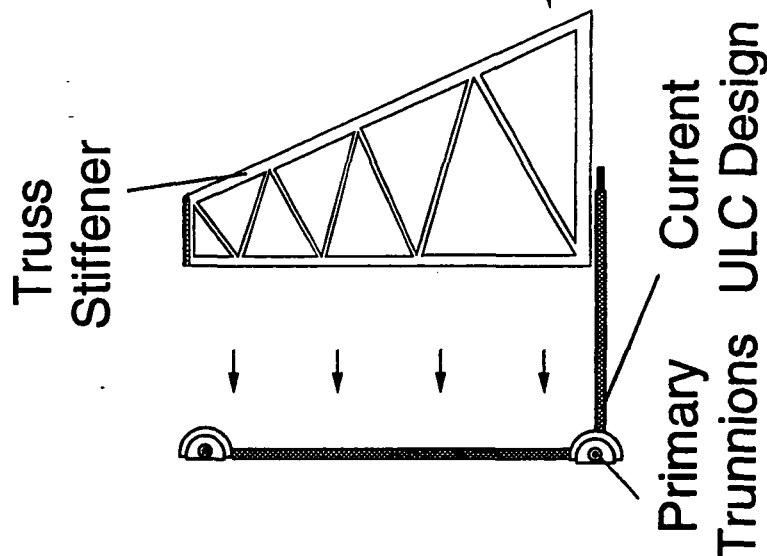
End-Mounted ULC

BOEING

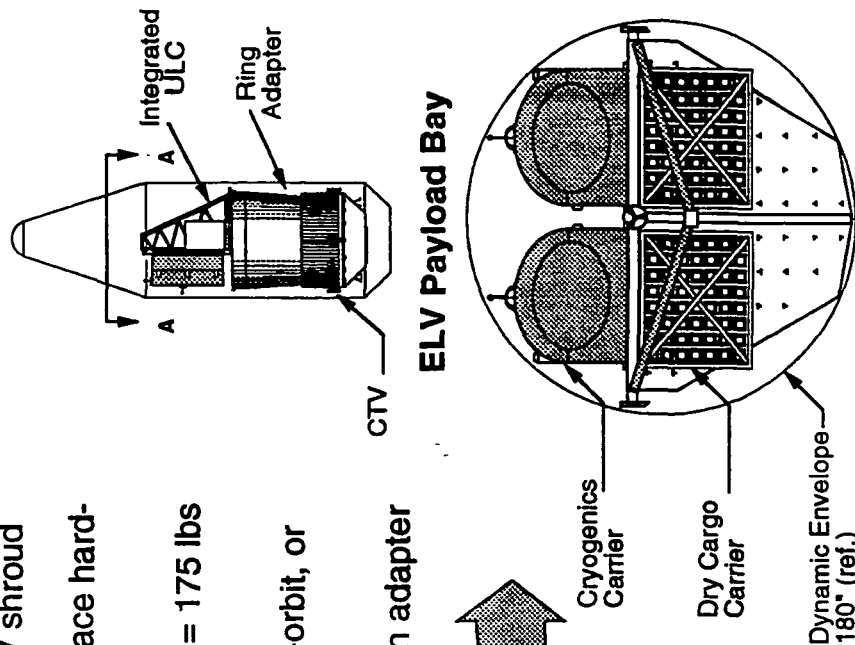
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CHARACTERISTICS

- ULC mounted longitudinally in ELV shroud
 - ULC to CTV adapter
 - Adapter attaches to ULC front face hard-points
- ULC modifications (truss stiffener) = 175 lbs
- STS return capability retained
 - Trunnion/Keel pins installed on-orbit, or
 - Shroud blisters around pins
- Power from CTV and/or batteries in adapter



Mass Properties	
Current ULC Design	3,445
Modifications	175
Cargo	15,565
TOTAL:	19,185



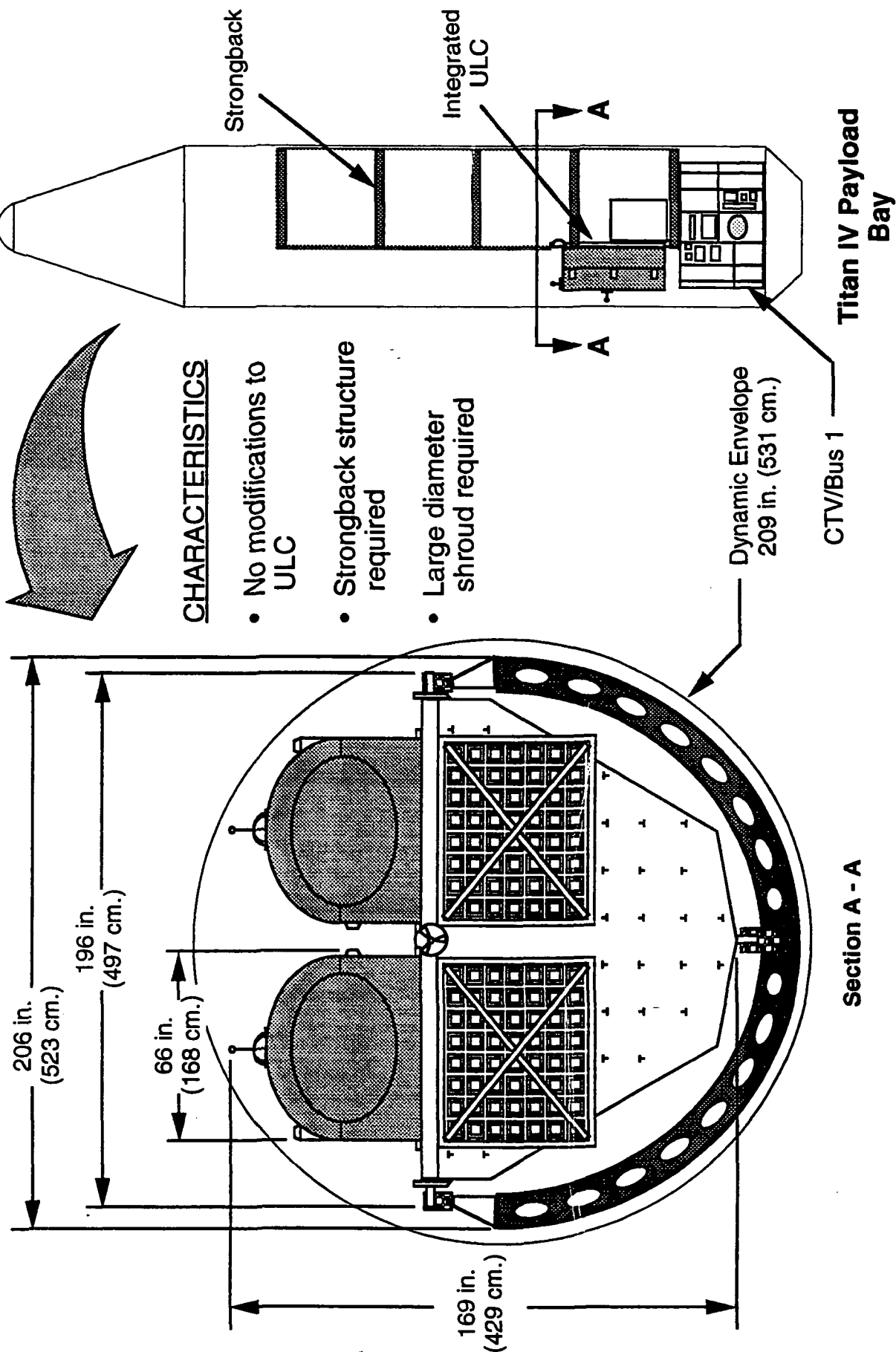
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Strongback-Mounted ULC

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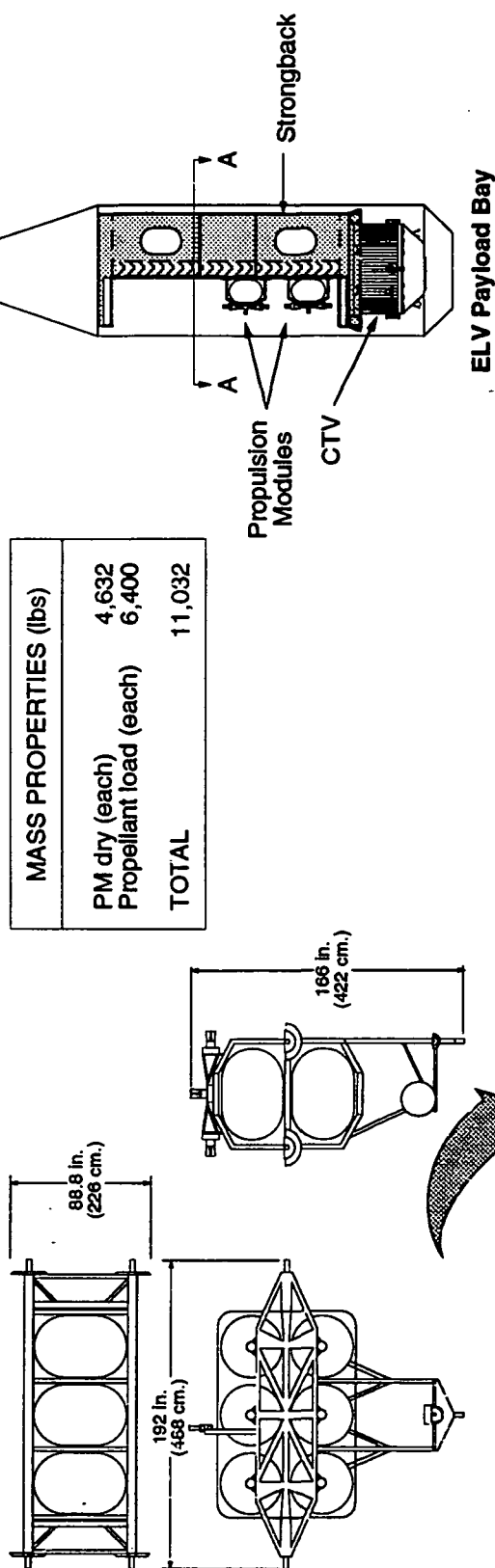


End-mounting a pair of PMs would require more than minimum mods to the carrier, so we opted for a strongback installation as the minimum mod concept. An end-mounted concept is shown in the next section.

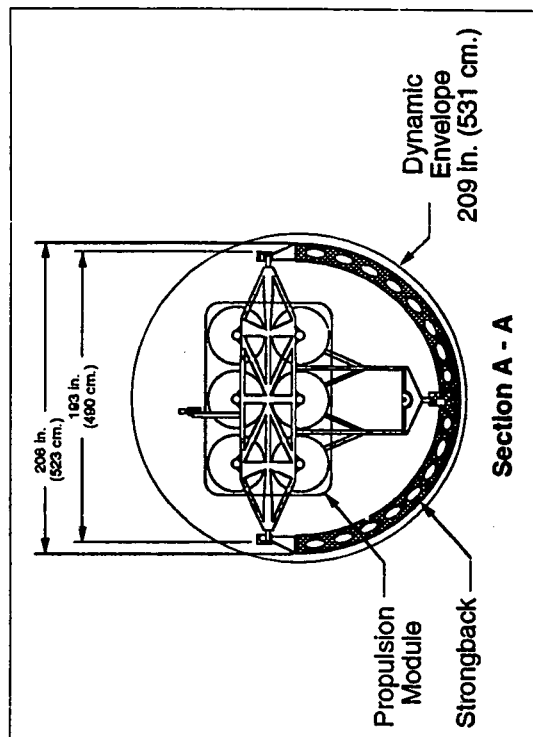
Strongback-Mounted PM

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MASS PROPERTIES (lbs)		
PM dry (each)	4,632	
Propellant load (each)	6,400	
TOTAL	11,032	



CHARACTERISTICS

- No modifications to PM.
- Strongback attaches to CTV adapter and picks up PM trunnion and keel pins.
- STS return capability retained.
- Increase in ELV shroud diameter required.

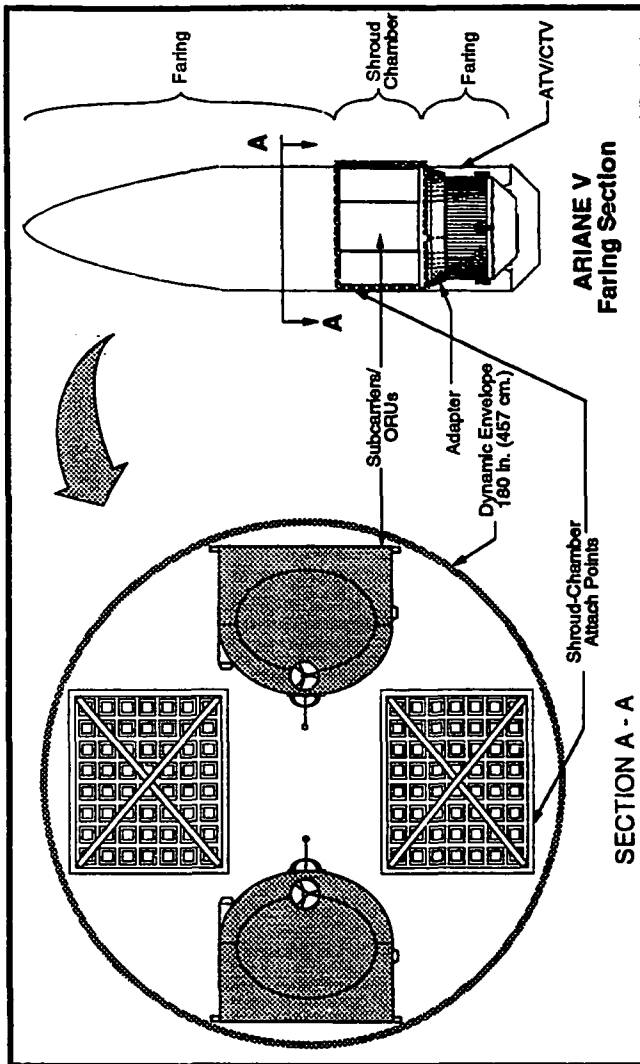
The following section describes our ELV-optimized unpressurized carriers.

Some of these options require reaching (either EVA or RMS) inside the ULC to release subcarriers or ORUs. An automated technique for releasing capture mechanisms by the RMS (as part of the grapple fitting) similar to that previously included in WP01 carrier design activity would simplify this process.

"Shroud Chamber" ULC Concepts

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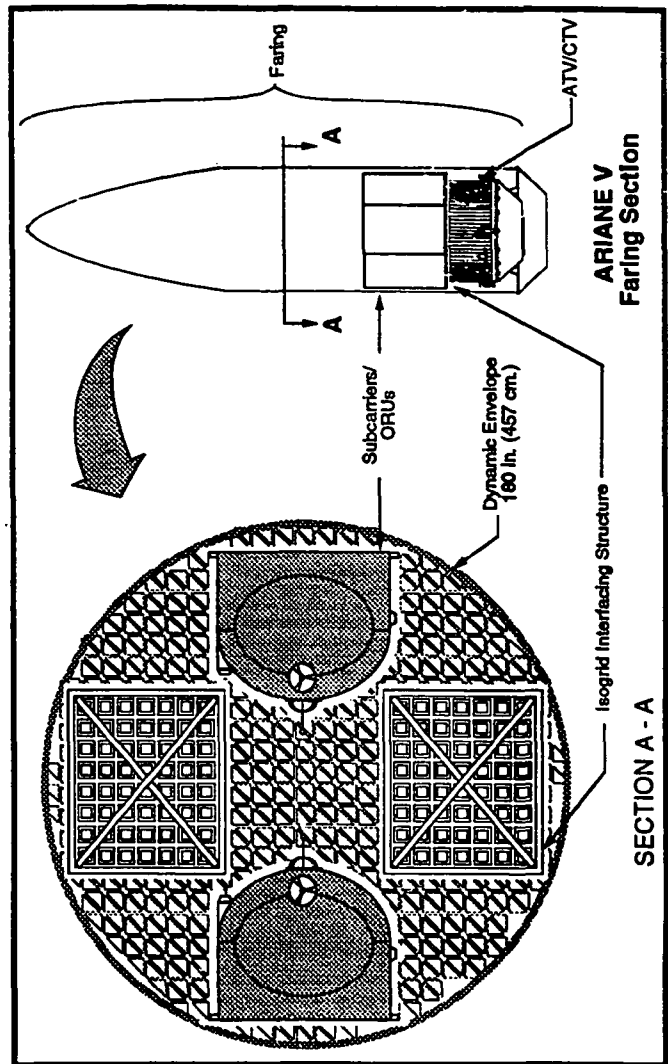
OPTION 1

CHARACTERISTICS

- "Shroud Chamber" structure is integral with shroud reducing overall weight
- ORU attachment same as current ULC design
- Fairing above and below shroud chamber is jettisoned at altitude
- Attachment area is increased 25% over current ULC design
- Shroud chamber length is 160 in. (same as current ULC design) to support cryogenic and dry cargo subcarriers
- Packaging options favor long, low, bottom-mounted ORUs/kits
- Requires CTV adapter

ISSUES

- Access to ORU capture mechanisms within shroud chamber
- Requires new ELV fairing design



OPTION 2

CHARACTERISTICS

- Plate is constructed to accommodate end-mounting of subcarriers and ORU's
- Plate transfers and distributes loads from payload to CTV
- At altitude, ELV fairing is jettisoned to expose payload and CTV
- Packaging options favor long, end-mountable ORUs/kits
- Does not require CTV adapter

ISSUES

- Requires modifying subcarriers/ORUs for end-mounting

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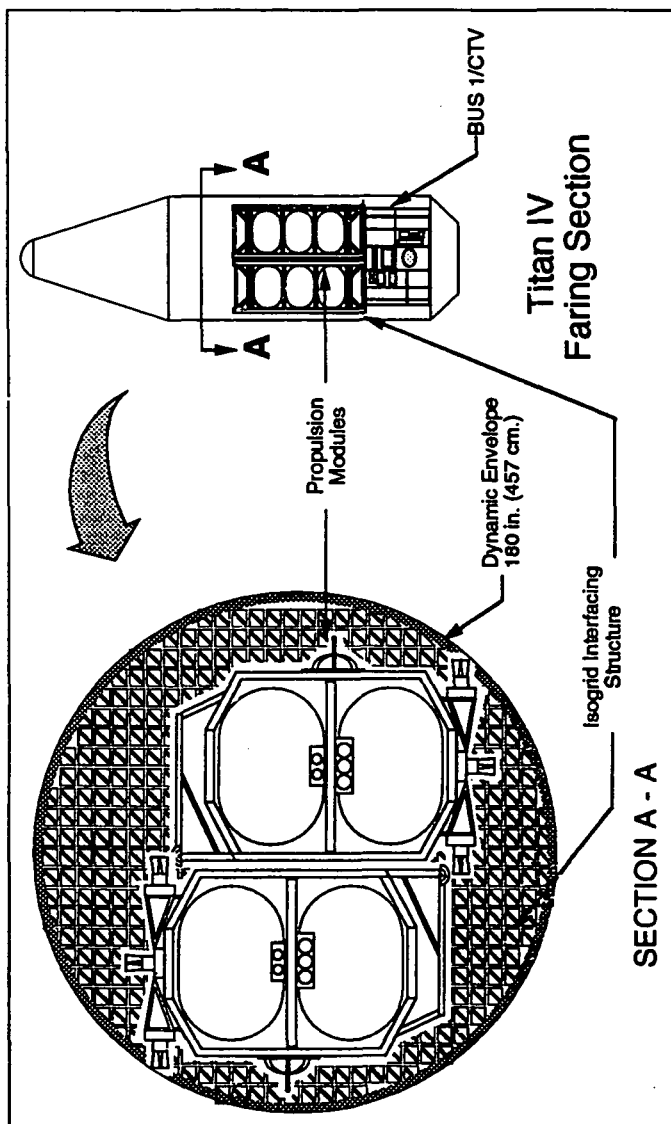
End-Mounted Propulsion Module

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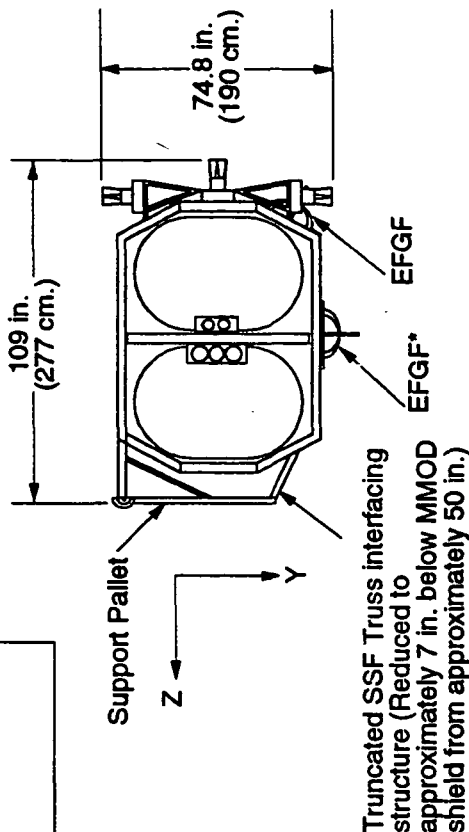
ISSUES

- PM support structure redesign.
- Violates structural limitation of PM fluid acquisition device (limited to PM Y-axis along velocity vector).



CHARACTERISTICS

- PMs modified for end-mounting and back-to-back support:
 - Support structure moved closer to tanks
 - SSF truss interface unchanged
- Interfacing transfers and distributes loads from Propulsion Module to CTV.
- At altitude, ELV fairing is jettisoned to expose Propulsion Modules and CTV.



* Only on MB-2 Forward Propulsion Module

Propulsion Module

The "edible" carrier term came from a NASA statement requesting innovative ideas for reducing the cost of logistics carriers and therefore SSF resupply. The term "edible" applies here because in this concept the carrier is in fact used for a different purpose after it arrives at SSF, as the term implies. Two concepts are shown, an edible ULC and an edible rack. Both are envisioned to be designed for two purposes, one to deliver logistics, and the other to be disassembled and reassembled into another structure. Potential applications for structures so constructed include external payload support and SSF system support.

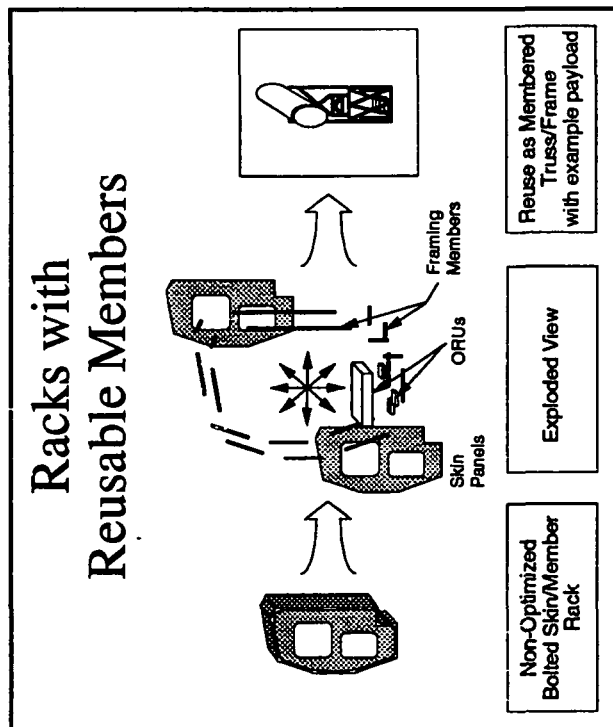
The size of the smallest reusable member in a reusable structure can vary. Our ideas include members from ULCs or racks a few inches long (as illustrated), planar sections from the current or new ULC concepts herein, or cylindrical sections from other new ULC concepts also described herein.

Reusability offers the benefit of substantial reduction in downmass (due to no carrier tare weight to be returned) at the cost of a slight increase in upmass (due to the relative inefficiency of structures designed for multiple uses compared to single-purpose structures).

"Edible" Carrier/Rack Concepts

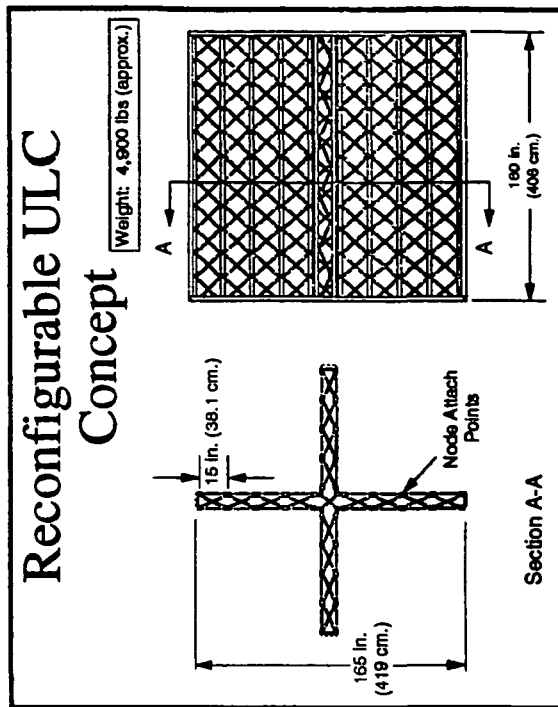
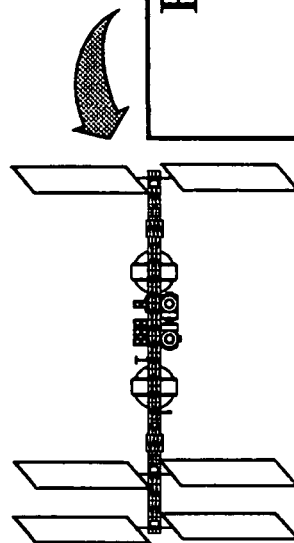
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CHARACTERISTICS

- ULC/racks designed to be disassembled on orbit and used to construct new structures.
- Optional ULC structural concepts.
 - Truss structure with reusable members. (as illustrated)
 - Similar to current ULC design with reusable planar sections.
 - Cylindrical ULC concepts with stacking sections.
- Optional rack structural concepts.
 - Bolted skin/members (as illustrated)
 - Built-up aluminum rack
- Allows reuse of ULCs/racks slated for destruction or return on STS.
- Eliminates ELV-delivered ULC/rack accumulation at SSF.
- Requires truss attachment structure.
- Applications for ULCs/racks reassembled on-orbit:
 - Truss substructure for payload attachment
 - SSF System support structure for SSF evolution.
- Other reusable items could include:
 - Captive fasteners
 - Individual Members (Curved and Straight)
 - Fittings
 - Connectors (Fluid/Electrical)



ISSUES:

- Not structurally efficient and may reduce payload mass to orbit.
- Intended on-orbit utility will drive design of ULC/rack configuration.
- Utility of constituent parts will not be 100%. Surplus items may include following:
 - Fittings
 - Plumbing
 - Power Lines
- Applications for space structures using shape-memory alloys.
- Contents of ULC/rack converted to another use must be removed through trash disposal or returned in another form.

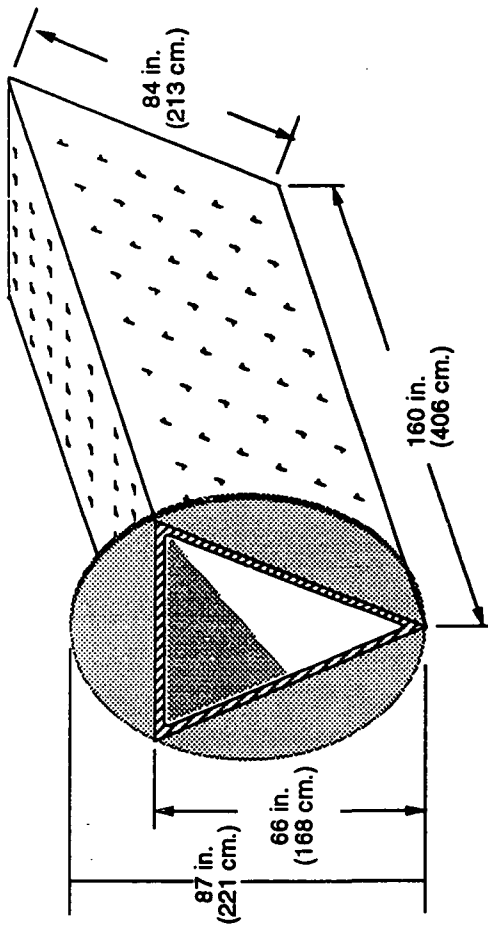
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"Triangular Beam" ULC Concept

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CHARACTERISTICS

- Dimensions of beam are optimized to allow largest ORUs to lie within dynamic envelope.
- Usable attachment area is approximately same as current ULC design.
- Weight: 3,200 lbs (approximate)

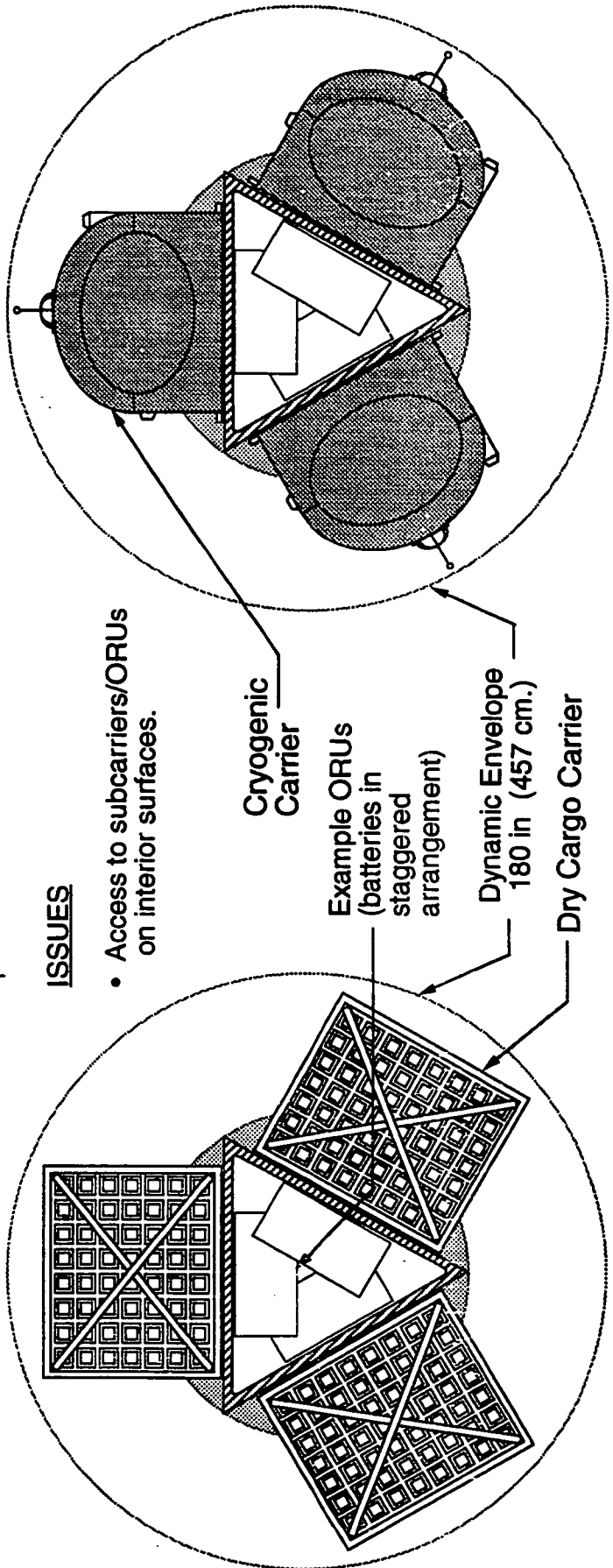


CHARACTERISTICS

- Attachment panels are same as current ULC design.
- Requires CTV adapter.

ISSUES

- Access to subcarriers/ORUs on interior surfaces.



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Unpressurized Logistics Carrier "Cruciform" Option

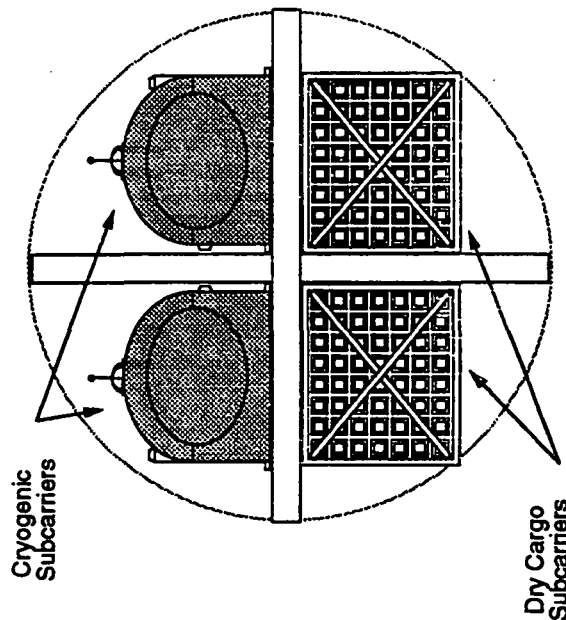
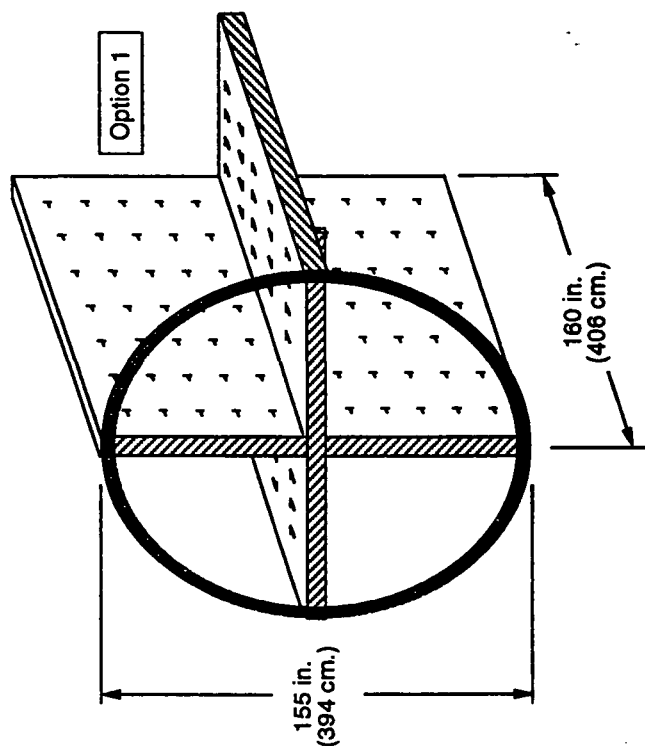
BOEING

CHARACTERISTICS

- Attachment panels are same as current ULC design.
- Usable attachment area is decreased 33 % over current ULC design.
- More uniform load distribution allows shorter CTV adapter than current ULC end-mounted design.
- Weight: 4,500 lbs (approximate)

ISSUE

- Reduced surface area.

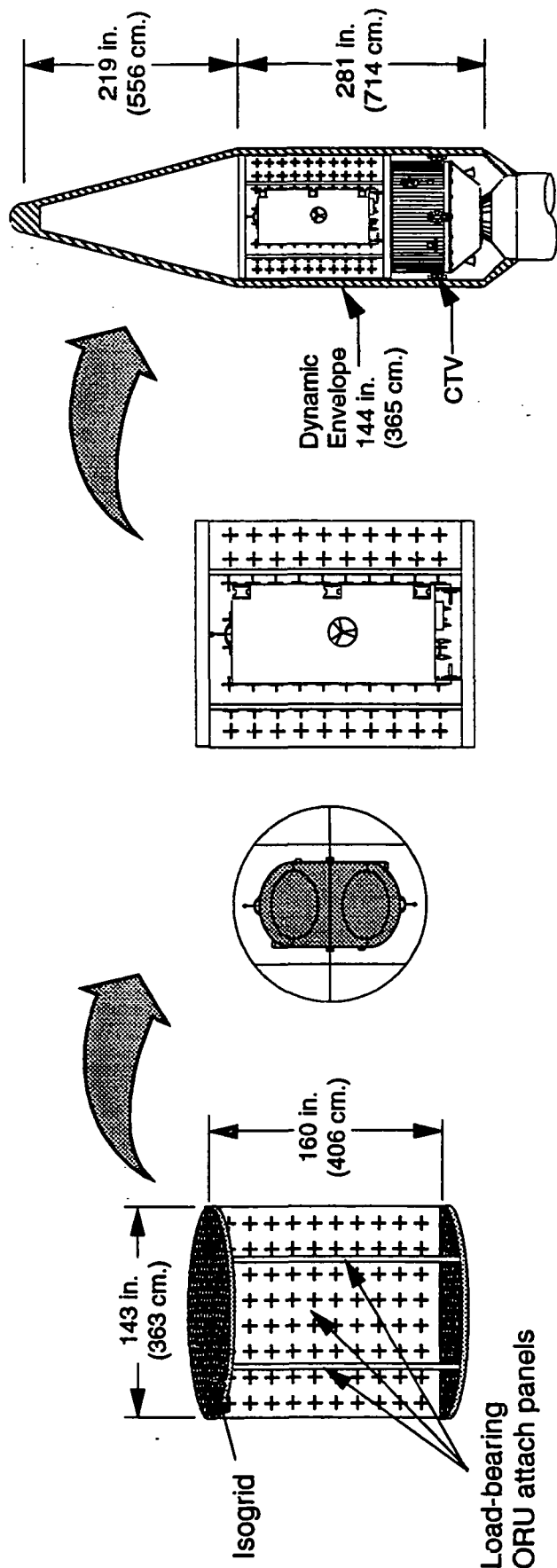


This chart illustrates a concept for a ULC configured for launch on an Atlas. The concept will require a new CTV (Titan and Ariane CTVs are 160" to 155" diameter) or a larger diameter Atlas shroud. The concept also suggests that further investigation of existing smaller launch vehicles and their capability to resupply SSF should be made considering number of launches and cost.

Small ULC (Atlas IIA Lanced)

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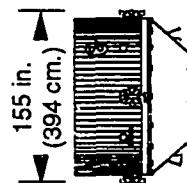
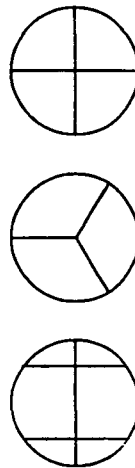
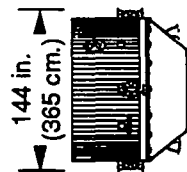
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Atlas IIA

CHARACTERISTICS

- Attach planes provide area for ORU packaging as well as support for upper ORU mounting surface
- ORU attachment same as current ULC design
- Attach planes could be reconfigurable to allow for a variety of different-sized ORUs

Optional Configurations


CURRENT

NEW

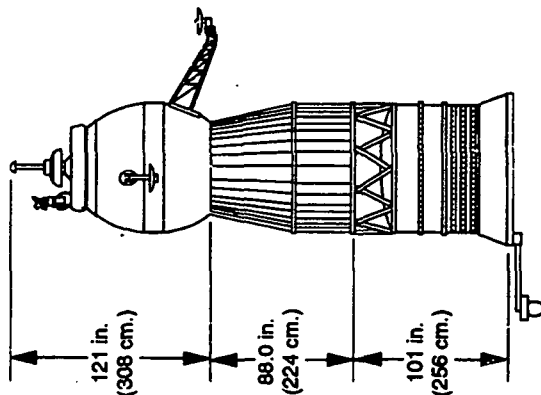
ISSUES

- Requires reduced diameter CTV
- Lengthened shroud required for:
 - ULC carrying COC/CNC (~ 160 in.)
 - CTV based on ATV (97 in. axial length)
 - 281 in. exceeds current 165 in. cylindrical length of shroud
- Relocation of subcarrier grapple fixtures may be necessary
- Weight: 2,500 lbs (approximately)

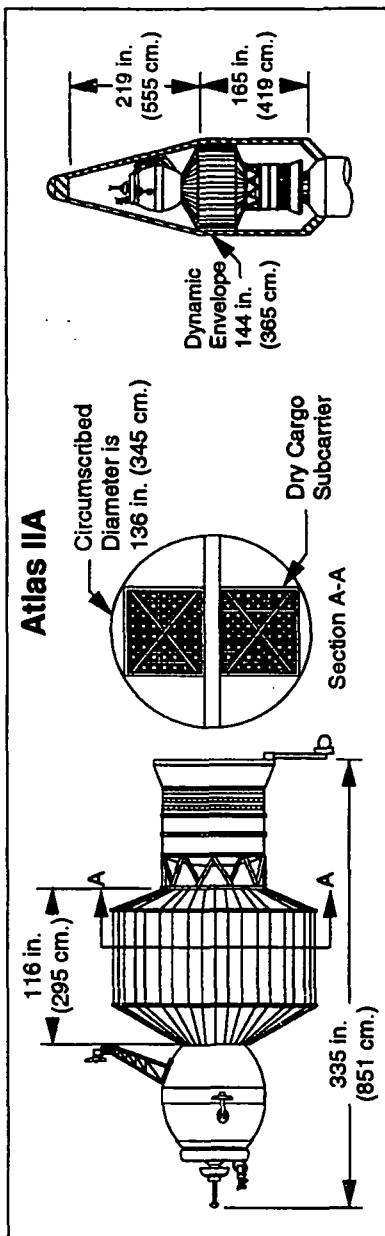
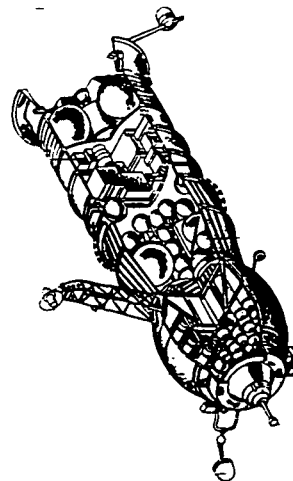
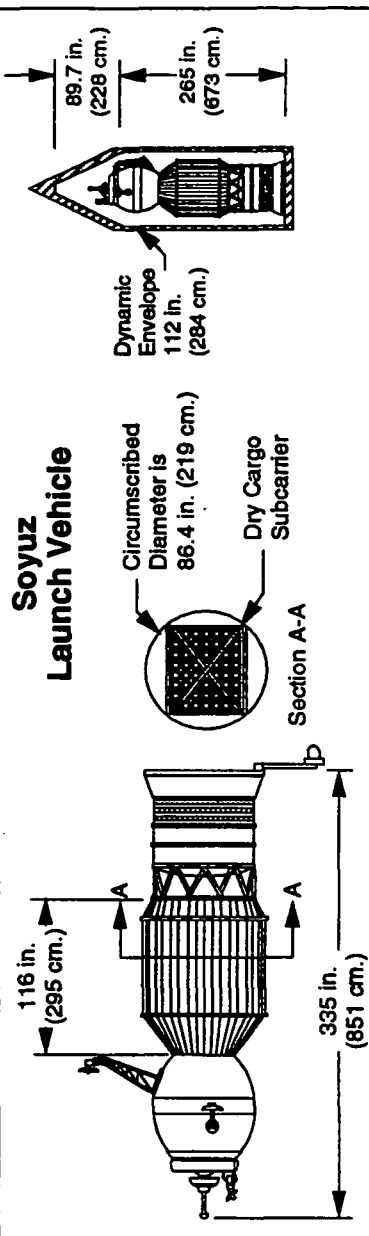
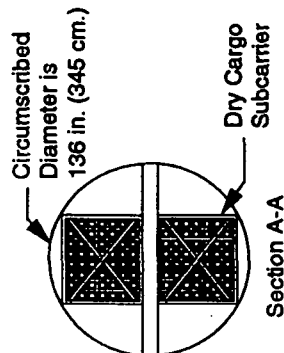
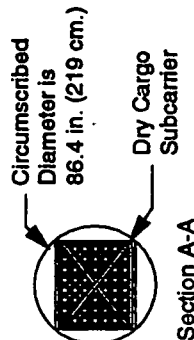
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Progress ULC

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**PROGRESS**

- 8.9 ft. (2.7 m) dia., 25.9 ft. (7.9 m) long
- 15,400 lb (7000 kg.) tare, 5600 lb (2,300 kg.) cargo

**Atlas IIA****Soyuz Launch Vehicle****CHARACTERISTICS**

- Replace Progress unpressurized section with ULC
 - Small ULC (< 9 ft. dia.) for Soyuz launch vehicle
 - Standard ULC (< 15 ft. dia.) for Titan IV/Ariane V
- Progress provides orbit maneuvering capability --- no CTV required.
- ORU/subcarrier attachment same as current ULC design.
- Progress transports payload to SSF RMS.

ISSUES:

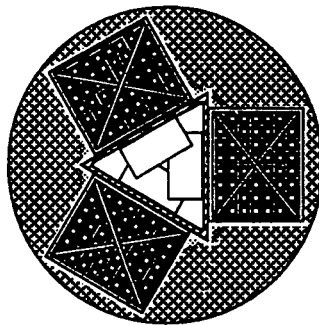
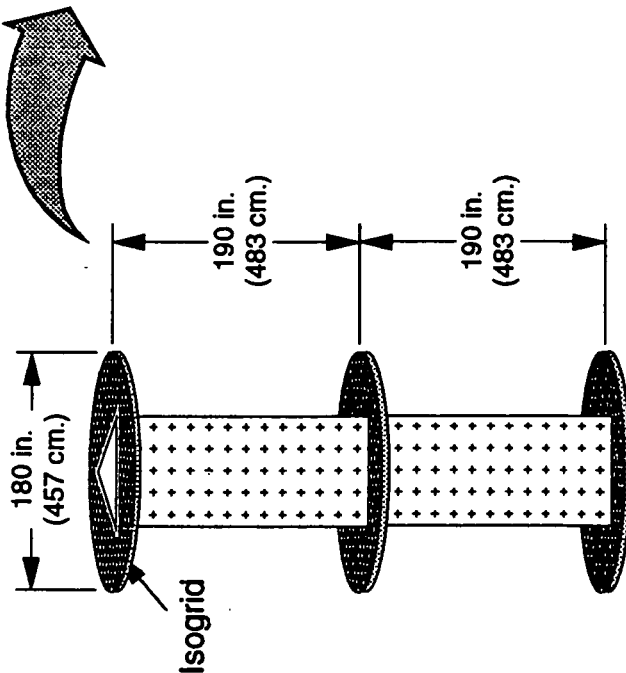
- Progress cargo weight limitations.
- Launch vehicle integration.
- ORU subcarrier transport to Soyuz launch site.
- Progress interface with other launch vehicle.

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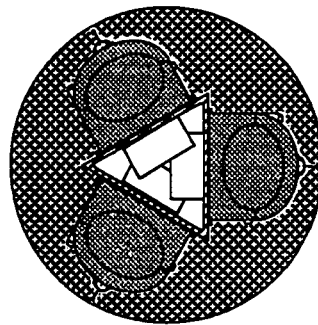
Stacked "Triangular Beam" ULC

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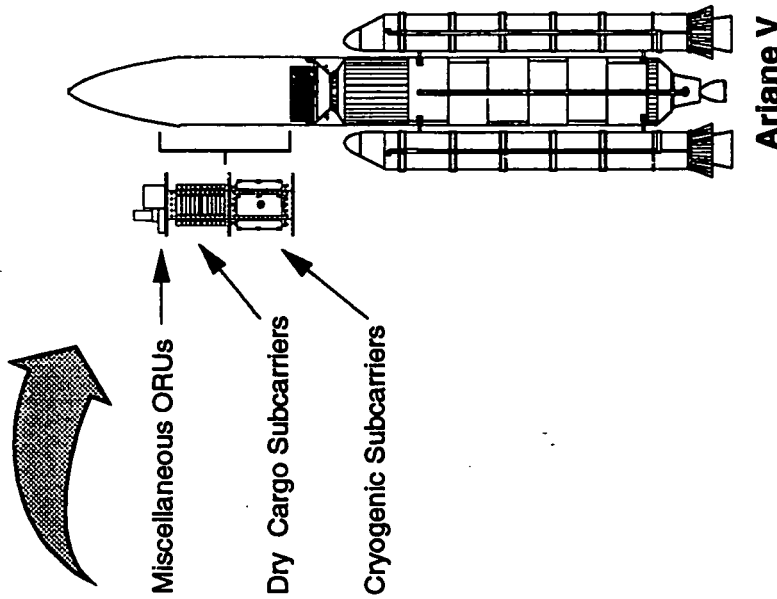
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Upper Deck Payload



Lower Deck Payload



Ariane V

ISSUES

- Access to subcarriers/ORUs on interior surfaces.

CHARACTERISTICS

- Usable attachment area is approximately same as current ULC design.
- Optimizes payload for Ariane V.
- Weight: 6,400 lbs (approximate)
- Attachment panels are same as current ULC design.
- Requires CTV adapter.
- Dimensions of beam are optimized to allow largest ORUs to lie within dynamic envelope.

Weights analyses of two potential STS/ELV logistics upmass scenarios were completed. The specific vehicle and carrier/cargo mixes were provided by NASA. The downmass scenario assumes some trash disposal on each flight prior to reentry to not exceed STS landing weight limits. Weight analysis on the downmass scenario was not performed.

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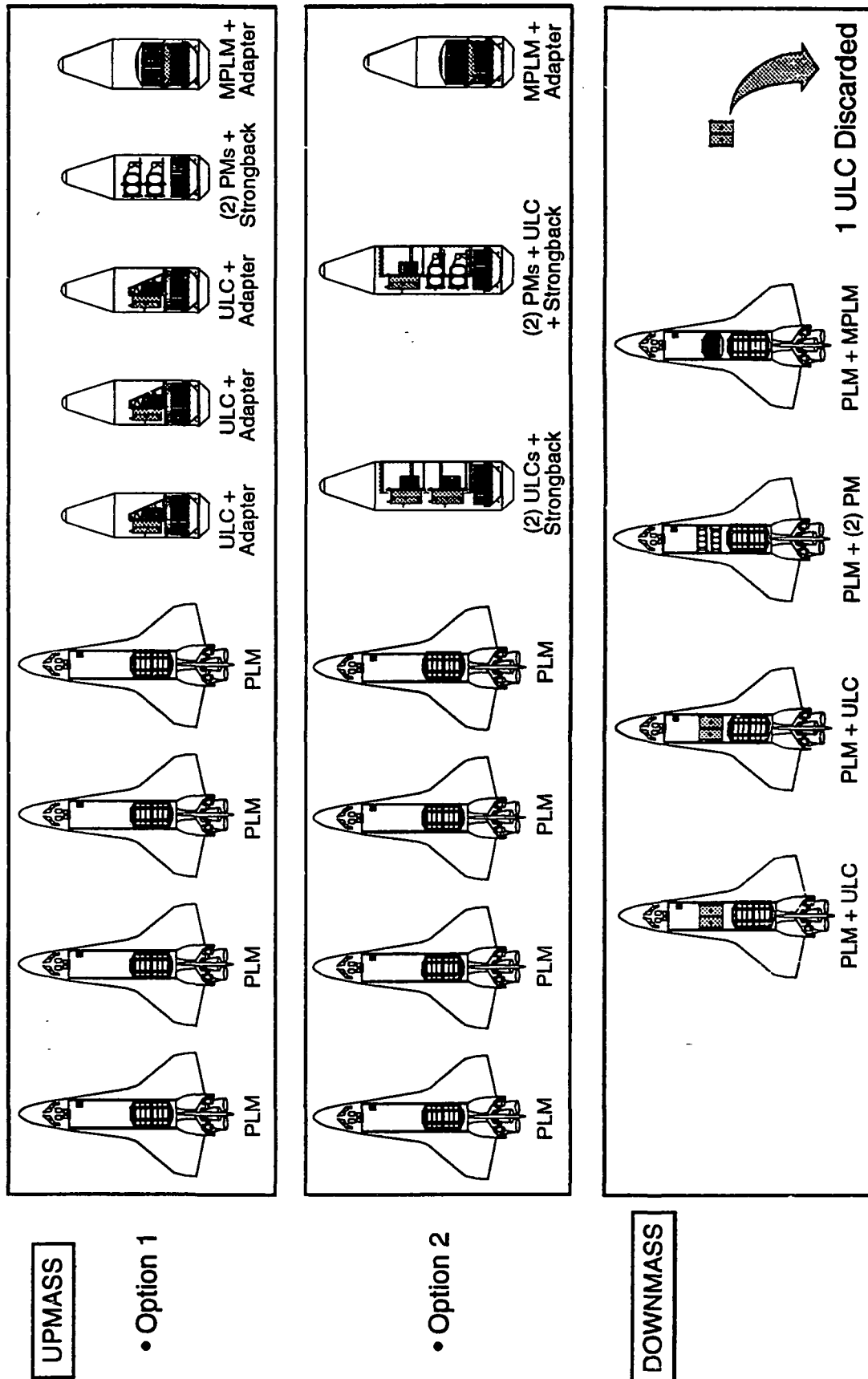
STS/ELV Mixed Fleet Logistics Scenario Evaluation---Mass Properties

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Vehicle Mix Logistics Scenario

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Logistics Delivery Option 1 Mass Properties

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ITEM	STS DELIVERED				ELV DELIVERED				
	1	2	3	4	5	6	7	8	9
	PLM	PLM	PLM	PLM	ULC	ULC	ULC	PM (2)	MPLM
Existing Carrier Tare Modifications	11,498	11,498	11,498	11,498	3,445	3,445	3,445	9,264	8,346
Cargo	22,886	22,886	22,886	22,886	15,565	15,565	15,565	12,800	9,275
Subtotal Carrier	34,384	34,384	34,384	34,384	19,185	19,185	19,185	22,064	17,816
CTV	-	-	-	-	13,342	13,342	13,342	13,342	13,342
Adapter	-	-	-	-	1,340	1,340	1,340	-	780
Batteries (Ag-Zn)	-	-	-	-	-	-	-	-	1,916
BMRs	-	-	-	-	-	-	-	-	329
Strongback	-	-	-	-	-	-	-	4370 ⁴	-
Vehicle Fairing Modifications	-	-	-	-	-	-	-	200	-
Subtotal ASE	-	-	-	-	14,682	14,682	14,682	17,912	16,367
TOTAL PAYLOAD	34,384	34,384	34,384	34,384	33,867	33,867	33,867	39,976	34,183
VEHICLE CAPABILITY	37,800 ³	37,800 ³	37,800 ³	37,800 ³	48,655 ²	48,655 ²	48,655 ²	48,655 ²	48,655 ²
MARGIN	3,416	3,416	3,416	3,416	14,788	14,788	14,788	8,679	14,472

1. ATV from 100 nmi. circular to 220 nmi.
2. Titan IV with SRMU to 100 nmi. circular.
3. To 220 nmi.
4. From MMC, "Titan Support for SSF," Aug. 91.

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Logistics Delivery Option 2 Mass Properties

BOEING

ITEM	STS DELIVERED				ELV DELIVERED		
	1	2	3	4	5	6	7
	PLM	PLM	PLM	PLM	ULC (2)	ULC + (2) PM	MPLM
Existing Carrier Tare Modifications	11,498	11,498	11,498	11,498	6,890	12,709	8,346 195
Cargo	22,886	22,886	22,886	22,886	31,130	28,365	9,275
Subtotal Carrier	34,384	34,384	34,384	34,384	38,020	41,074	17,816
CTV ¹	-	-	-	-	13,342	13,342	13,342
Adapter	-	-	-	-	-	-	780
Batteries (Ag-Zn)	-	-	-	-	-	-	1916
BMRs	-	-	-	-	-	-	329
Strongback	-	-	-	-	8,740 ⁴	8,740 ⁴	-
Vehicle Fairing Modifications	-	-	-	-	200	200	-
Subtotal ASE	-	-	-	-	22,282	22,282	16,367
TOTAL PAYLOAD	34,384	34,384	34,384	34,384	60,302	63,356	34,183
VEHICLE CAPABILITY	37,800 ³	37,800 ³	37,800 ³	37,800 ³			48,655 ²
MARGIN	3,416	3,416	3,416	3,416			14,472

1. ATV from 100 nmi. circular to 220 nmi.
2. Titan IV with SRMU to 100 nmi. circular.
3. To 220 nmi.
4. Double strongback weight from MMC, "Titan Support for SSF," Aug. 91.

An issue mentioned earlier associated with delivering carriers to SSF by ELV and returning them by STS is twofold: (1) delay in arrival of STS means carriers with contents to be returned in STS may accumulate at SSF (taking up valuable attachment locations) and after exposure must be structurally and otherwise verified prior to STS reentry, and (2) in order to pick up a carrier at SSF and return it, the STS must either make a special trip or have completed another mission and released its primary cargo, then swing by SSF, checkout and reintegrate carriers with contents to be returned (with required ASE either available at SSF or already installed), and return.

Two alternative methods for returning carriers and other items to Earth without STS are described. The concepts include a vehicle to transport contents into a destructive reentry, and a vehicle providing safe return of contents autonomously.

Alternate Carrier Return Concepts

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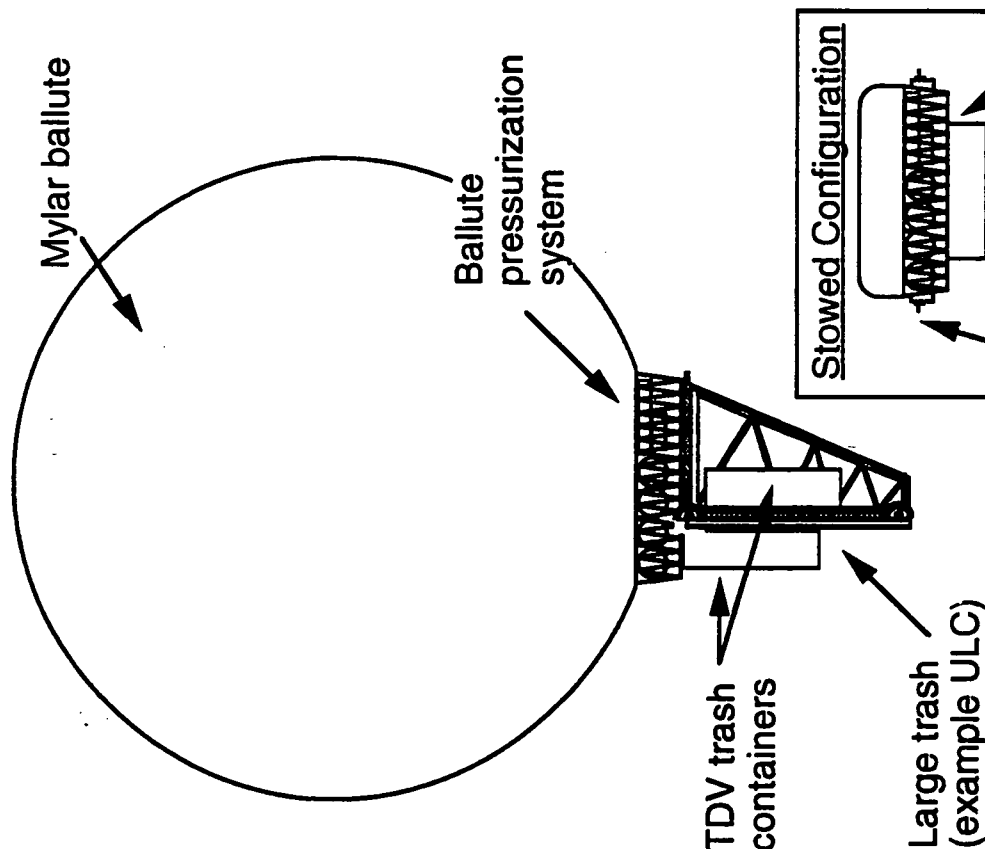
- Trash Disposal Concept
- Ballistic Return of Logistics Elements

A trash disposal technique has been conceived that will make ELV resupply of SSF more effective by reducing the amount of materials that must be returned by STS. This trash disposal concept is a simple, low-cost technique of transporting trash and other non-returnable items to a destructive reentry. The concept makes use of a ballute providing high atmospheric drag. The trash disposal vehicle (TDV) will carry its contents through a slow, passive reentry process, and burn up during the final stages.

Trash Disposal Concept

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Trash Disposal Vehicle



Characteristics

- Trash disposal vehicle (TDV) launched in STS or ELV, stowed at SSF externally
- Items to be destroyed placed in trash disposal vehicle (TDV) trash container or secured to TDV hardpoints
 - Load trash container IVA
 - Install container/load large items EVA/RMS
- TDV jettisoned when SSF at lowest orbit (after STS safely away)---small Δv imparted (springs or compressed gas)
- TDV balloon inflated after SSF reboosted
- TDV/trash deorbit/burn up due to atmospheric drag
- Mylar balloon easily tracked with radar
- Balloon inflated with waste gas (reducing gas expelled around SSF--compression system required), or compressed O₂ or N₂ (providing emergency gas supply for crew--compressed on ground)
- Drag-inducing device could be ballute or antenna-type aerobrake
- Mass/material limitations on trash

Issues

- Safety concerns of pressurized bottles
- Time/trajectory/ballute shape studies required

An autonomous return vehicle has been conceived that will return its contents safely to a water landing. The vehicle is stored at SSF, and returns carriers, modules, and their contents without STS.

Ballistic Return of Logistics Elements

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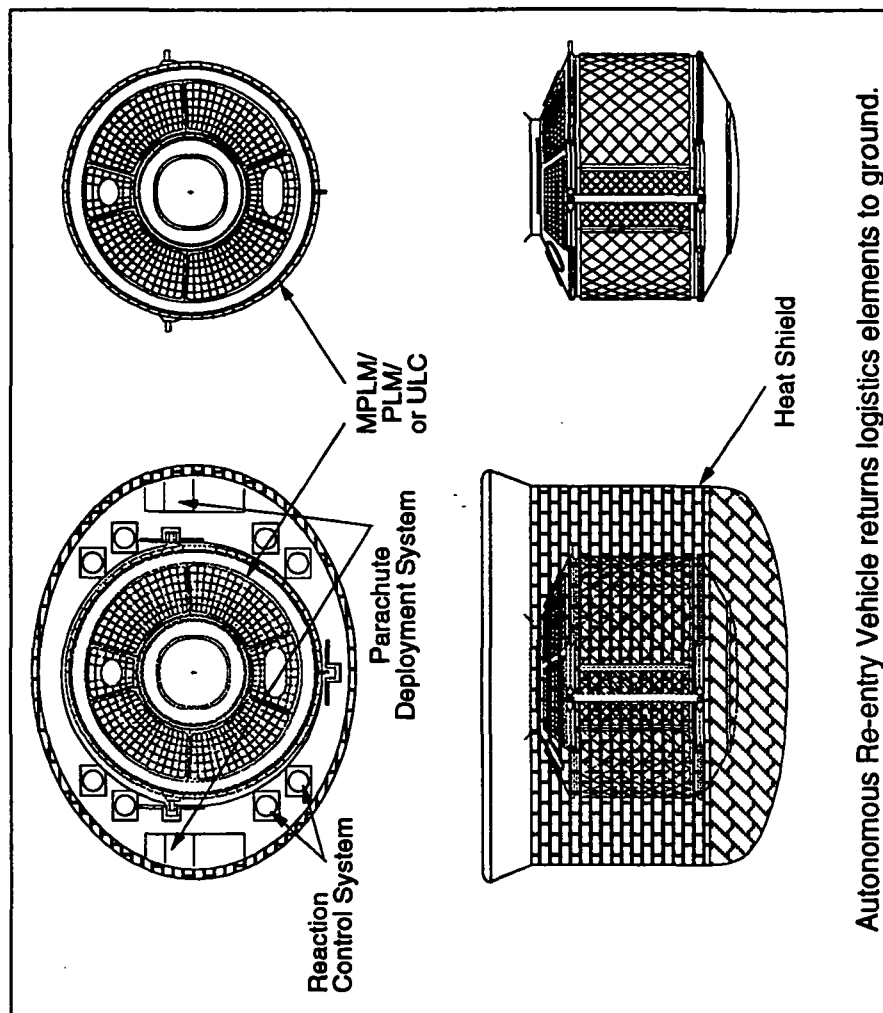
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CHARACTERISTICS

- PLM/MPLM/ULC delivered to SSF on ELV
- Aerobrake/Heat Shield/Reaction Control System (RCS) delivered on ELV
- Return Vehicle integrated on orbit
- Logistics element recovered after water landing
- Eliminates accumulation of ELV-delivered logistics carriers at SSF or need to destroy after use

ISSUES

- On-orbit integration of return vehicle
- Aerobrake/Heat Shield/RCS vehicle development



Autonomous Re-entry Vehicle returns logistics elements to ground.

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Summary

- Existing STS logistics carriers evaluated for ELV-compatibility
- New ELV carriers conceptualized
- Study complete

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